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Infiltration Land Treatment of Stabilization Pond Effluent

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Brookings, South Dakota

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INFILTRATION LAND TREATMENT OF STABILIZATION POND EFFLUENT

by

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Grant Number R803804.

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A pilot rapid infiltration wastewater treatment system consisting of three 0.07 hectare basins was operated for four seasons at Brookings, South Dakota. The objectives of the study were to demonstrate that rapid infiltration land treatment could upgrade stabilization pond effluent to meet stringent effluent requirements and to identify winter operating constraints for the system.

After passing through 1.3 m of the soil profile, the following quality was observed: BOD_5 was less than 4 mg/l all of the time and generally less than 2 mg/l; the suspended solids rarely exceeded 4 mg/l; total phosphorus rarely exceeded 1 mg/l; ammoniacal nitrogen was less than 2 mg/l and usually less than 1.1 mg/l; and nitrate nitrogen rarely exceeded 10 mg/l.

Winter operation of the pilot units with intermittent applications was not practical. Ice accumulated with each successive flooding and operation had to be discontinued in early January.

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FOREWORD

The Environmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies which optimize the use of the nation's land and water resources while minimizing the threat of pollution.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of research programs which include the development of soil systems for the treatment and management of municipal wastewater.

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Although land application of municipal wastewaters has been practiced for years, there has been a growing interest in recent years. The use of land application has received major impetus with the passage of the 1972 amendments to the Federal Water Pollution Control Act. The 1977 amendments to the Act gave further encouragement to the use of land application and provided incentives for the funding of these systems through the construction grants program. Rapid infiltration is one of the lesser developed land treatment technologies. Questions still exist regarding treatment effectiveness in northern climates. This study advances the knowledge on how to design and manage rapid infiltration wastewater treatment systems.

This report contributes to the knowledge which is essential for the EPA to meet the requirements of environmental laws and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental Research Laboratory

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ABSTRACT

A pilot infiltration-percolation unit consisting of three basins with a total area of about 0.2 hectare (0.5 acre) was operated for four seasons at Brookings, South Dakota. The objectives of the study were to demonstrate that infiltration land treatment could successfully upgrade stabilization pond effluents to meet stringent effluent requirements, to determine acceptable loading rates for the silty clay loam soil at the site and to identify winter operating constraints for the system.

The unit was constructed with earthen banks graded to a height of about 0.9m (3ft). Perforated plastic underdrains installed under each basin were used for collection of samples and to control the high groundwater table of the area. Once-per-week inundation of the pilot units during the 1975 and 1976 seasons to accomplish a weekly loading of 0.6m (2 ft) of wastewater resulted in a rest period of about six days per week. During the 1977 and 1978 seasons, wastewater was applied at approximately two-day intervals with three 0.2m(8in) applications resulting in near continuous wetting of the basins. Samples were collected weekly from the influent and two sets of drains and analyses included BOD, SS, pH, conductivity, ortho and total phosphorus, kjeldahl, ammonia and nitrate nitrogen. During the 1978 season, common inorganic ions were measured to determine the cause of a 10 percent increase in conductivity for the renovated water.

Interpretations of data could be made to determine the influence of scarified vs undisturbed natural cover conditions for the basins as well as comparing renovated water quality from drains installed at depths of 0.8 and 1.3 m (2.5 and 4.5 ft). Oxidation of ammonia nitrogen to nitrates without nitrogen removal occurred with weekly wastewater applications in 1975 and 1976 as compared to about 80 percent nitrogen removal with more frequent wastewater applications. Infiltration rates for the basins with near continuous wetting of the soil for several weeks was substantially lower than rates recorded with a weekly flooding schedule. Piezometer measurements evaluated groundwater response to the wastewater applications and demonstrated that drains were capable of controlling a high water-table situation.

Winter operation of the pilot units with intermittent flooding was not practical because wastewater from the stabilization ponds was near freezing when applied. Ice accumulated with each successive flooding and wastewater applications had to be discontinued in early January.

This report was submitted in fulfillment of Project Number R803804 by the Civil Engineering Department, South Dakota State University. The report covers the period from June 15, 1975 through November 15, 1978 and the work was completed as of May 7, 1980.

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Far too numerous to mention but much appreciated are the many departments and colleagues at South Dakota State University who provided equipment and advice during the course of this investigation. Special recognition is extended to the past graduate students of the Civil Engineering Department at South Dakota State University who assisted in the construction and operation of the pilot units and/or the sampling, analyses and data collection for the project. Partners and equal contributors to the research project were Donald Voogt, Dayton Alsaker, Eugene Miller, Alan Larson, John Dickinson, Larry DeMers, Brian Borgstadt, Richard Seas, Thomas Drake and Richard Waples who reported on specific aspects of the project in their individual Master of Science theses. Lon Hesla, Delvin DeBoer, Gary Bleeker and Terry Kirschenman also made important contributions as they assisted in the collection and analysis of samples or data evaluation during the course of the study. Special appreciation is given to Lillian Hellickson for her editorial assistance and typing of the many progress reports required and of the draft of this report.

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SECTION 1

INTRODUCTION

Stabilization ponds are the predominant type of treatment employed by municipalities of 5,000 persons or less in the upper great plains region. However, the ability of these ponds to meet present and future effluent standards is limited. A rapid infiltration system, designed and operated to make the maximum use of an available in-place soil system, is considered as a potentially economical solution to meet future effluent requirements of stabilization ponds.

Of the 180 stabilization ponds operating in South Dakota, about 40 have not discharged for at least one year according to recent reports. These "no-discharge" facilities would actually be infiltration ponds in South Dakota since usual evaporation, precipitation and wastewater flow rates suggest an annual seepage rate in excess of 1.8 meters (m) (6 feet (ft)). Other ponds are also believed to exceed the 1.6 millimeters (mm)/day (1/16 inches (in)/day) allowable seepage rate. These losses to groundwater do not, however, imply contamination of groundwater since earlier studies (1) revealed the seepage to be of excellent quality.

In the early 1970's, utilities personnel of Brookings, South Dakota anticipated difficulty in meeting future wastewater effluent quality standards. Brookings, population about 16,000, is served by a trickling filter treatment facility followed by two stabilization ponds which operate in series. Effluent quality is quite seasonal in nature and more stringent discharge standards were expected. In 1974 through a cooperative effort between the city and South Dakota State University, and with financial support from the Water Resources Institute at South Dakota State University, a land-infiltration pilot unit was constructed near the stabilization pond at Brookings. Environmental Protection Agency (EPA) funded the subsequent research with the overall objective to determine if a rapid infiltration system of land treatment could serve as a practicable means of upgrading secondary effluents particularly from wastewater stabilization ponds in the upper great plains region. The original specific objectives were as follows:

1. Demonstrate the use of infiltration-percolation land disposal as a means of upgrading existing secondary treatment to meet new effluent standards for five-day biochemical oxygen demand (BOD_5), suspended solids (SS), and fecal coliforms while removing phosphorus and oxidizing ammonia nitrogen (NH_3-N), to nitrate (NO_3-N), to meet new ammonia (NH_3) standards;
2. Determine acceptable loading rates for a scarified and undisturbed silty loam soil, underdrained with perforated pipe at a depth of

0.8 m (30 in), for climatic conditions similar to those at Brookings, South Dakota; and,

3. Identify winter operating constraints imposed by the climatic conditions at this site.

The research project was active for four seasons and data collection was completed in late 1978. During that period, various aspects of the research project were reported in detail by participating graduate students (2, 3, 4, 5, 6, 7, 8, 9, 10, 11). This report summarizes data from the project with some discussion of winter operating constraints and appropriate design considerations for infiltration-percolation treatment.

Figure 1. Aerial photograph of research area depicting present topography - August, 1974. (A-rapid infiltration units, B-stabilization ponds, C-airport runway extension, D-old channel of Six-Mile Creek, E-new channel of Six-Mile Creek).

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Operation of the pilot infiltration-percolation basins for four seasons demonstrated that a moderate-rate system constructed at a site with a silty clay loam soil and a high water table can serve as a practical treatment alternative for secondary effluents, particularly stabilization pond effluent. A drained and pumped system would appear to control a high water table situation although careful placement of the drains to prevent short-circuiting of applied wastewater is essential.

Loading rates of 0.6 m/week (24 in/week) were easily maintained from spring through fall when single weekly wastewater applications were used. When the soil was sustained in a near-saturated condition, infiltration rates diminished from about 15 mm/hour (0.55 in/hour), the rate representative of an eight-day test, to about 3 mm/hour (0.1 in/hour). Equilibrium loading rates for a nearly continuously wetted area would be about 45 centimeter (cm)/week (18 in/week) for the scarified basins compared to 60 cm/week (24 in/week) for unscarified soils containing the highly organic surface layer.

The treatment provided to the stabilization pond effluent by the infiltration units was sufficient to meet most point-discharge effluent standards. Nitrogen removals as high as 80 percent were achieved by frequent wastewater applications which promoted nitrification-denitrification conditions. The improved nitrogen removal was, however, associated with the lower infiltration rates. Nitrate limitations for groundwater were effectively met by changing the application frequency to prevent in-depth soil aeration.

Continuous winter operation of the pilot basins was not practical with stabilization pond effluent since the wastewater was near freezing when it was applied to the soil. Operational problems were experienced due to blizzards, accumulated ice, low infiltration rates and ice that would not float because it was anchored with weeds or frozen to the ground. In many cases, existing stabilization ponds could provide the preapplication treatment and the necessary emergency storage to carry through the most severe winters.

Based on the experiences of this pilot study, it is recommended that future construction should include installation of drains as deep as practical in a high-groundwater situation. Removal of the upper highly organic top soil should be avoided to maintain higher infiltration rates. If winter operation is considered, dikes should be constructed at sufficent height to allow a water layer to be maintained under initial ice formation to assure floating ice.

SECTION 3

SITE CHARACTERISTICS

The site of the pilot infiltration units was a level area representative of the adjacent flood plain near the stabilization pond at Brookings. Soil borings in the area revealed approximately 1.2 m (4 ft) of silty clay loam underlain with saturated coarse sandy gravel. The depth to normal groundwater varied from about 0.6 m - 1.2 m (2 ft to 4 ft) and was influenced by precipitation and water level of the nearby creek.

The preliminary selection of the site for the construction of the pilot infiltration-percolation basins included consideration of the following factors:

1. A comparatively level area because of the proposed construction method,
2. Soils representative of the area that might be used in actual construction of a plant-size facility,
3. A location near the present stabilization pond to avoid excessive piping to the site, and
4. An elevation that would allow application of wastewater without pumping as well as construction of underdrains in the units so that drainage could be sampled independently prior to gravity discharge to a nearby creek.

As shown in Figure 1, the location of the pilot infiltration units was between the stabilization ponds at Brookings and Six-Mile Creek. The site was on property owned by the city of Brookings, and it appeared to meet all of the criteria outlined above. Groundwater quality of the area was expected to be influenced by the pond and its effluent ditch to Six-Mile Creek. The creek channel in the area had been changed as a result of airport expansion. The soil was classified as poorly drained Lamoure silty clay loam.

According to soil survey information (12):

> The Lamoure soil in Brookings County is a somewhat poorly drained Chernozem-Humic Gley intergrade that has developed under tall grasses in 1.07 m (42 in) or more of medium-textured alluvium, which is underlain by mixed sand and gravel. It occurs on level and nearly level broad bottom lands and in shallow, narrow, dendritic drains that extend far back into the uplands.

> The Lamoure soils have an A_1 horizon of black, friable, strongly calcareous silt loam or silty clay loam. The A_1 horizon grades into a B_{2g} horizon of black to very dark gray, moderately to strongly calcareous silty clay loam that is of weak to moderate prismatic and blocky structure. The B_{2g} horizon overlies a very dark gray to gray weakly calcareous C_g horizon that grades into a D_g horizon of mixed sand and gravel...
>
> Many areas of Lamoure silty clay loam, nearly level, are used for corn and small grains, but many areas are in grass and used for pasture or hay.

An important characteristic of Lamoure silty clay loam is the cation exchange capacity which ranges from 30-43 milliequivalent (me)/100 grams (12) in the upper 1.2 m (48 in) of soil. Soil pH ranges from 7.5 to 7.7. Organic content ranges from 20 to 10 percent for soil samples from 2.5 cm to 84 cm (1 in to 33 in) in depth. The reported permeability of 10^{-6} cm/second (sec) to 10^{-8} cm/sec (12) would appear to be in error since a more recent soil survey reported a permeability of 1.4×10^{-4} cm/sec to 5.6×10^{-4} cm/sec (0.2 in/hour to 0.8 in/hour) for Lamoure silty clay loam soil. The soil has a high shrink-swell potential and an available water capacity of 0.14 cm/cm to 0.21 cm/cm of soil.

Climatic factors play an important part in the suitability of an infiltration-percolation system in this area. The following statements are from a climatological summary (13) for the area.

> Temperatures in the Brookings area have a large variation annually and occasionally from day to day. Temperatures usually rise above 38°C (100°F)in summer and drop to -29°C (-20°F) or lower in winter.
>
> A reading of -29°C or lower may be expected about two times a year in January and February and once a year in December. A -34°C (-30°F) or lower reading may occur about once in three years in January or February. The temperature may fail to climb above -18°C (0°F) during the day two times per year in January and about once each year in February and December.
>
> The average annual precipitation for Brookings is 52.3 cm (20.6 in), of which 41.8 cm (16.46 in) or 80 percent falls during the growing season (April-September).
>
> Seasonal snowfall averages 61 cm (24 in), but seasonal totals have ranged from 7.9 cm (3.1 in) during 1930-31 season to 184 cm (72.5 in) during 1968-69 season. Strong winds often accompany snowfall, causing large drifts in sheltered areas, while open fields remain bare.

The length of the growing season is 127 days with the average date of the first frost in the fall on September 21 and the last frost in the spring on

May 17. Daily mean temperatures are below 0°C from November 17 through March 21, a period of 114 days.

Thus, the pilot unit evaluated an infiltration-percolation system in an areas with rather severe site characteristics:

a. A high water table with an unsaturated zone of about 1 m, far less than the recommended 3 m minimum,
b. A silty clay loam soil whereas rapid infiltration systems are usually employed in sands and sandy loams and,
c. Severe winters with average temperatures below freezing for more than 114 days and extreme temperatures to a -30°C or lower.

SECTION 4

CONSTRUCTION AND OPERATION

The construction of the pilot basins consisted of grading the surface earth with the blade of a road maintainer to form dikes about 0.9 m (3 ft) in height. Initially, dikes were constructed to enclose the middle basin without disturbing the existing soil and vegetal cover of alfalfa and brome grass. Additional dikes were formed to enclose two adjacent pilot units with surfaces scraped free of the upper 9.2 m (8 in) of highly organic soil and vegetal cover. To prevent leakage and to define a measurable infiltration area, a plastic membrane was installed in the dikes and was covered with a soil layer. The resulting three basins shown in Figure 2, about 15 m by 45 m (50 ft by 150 ft) in size, were designated as north, middle and south for reference.

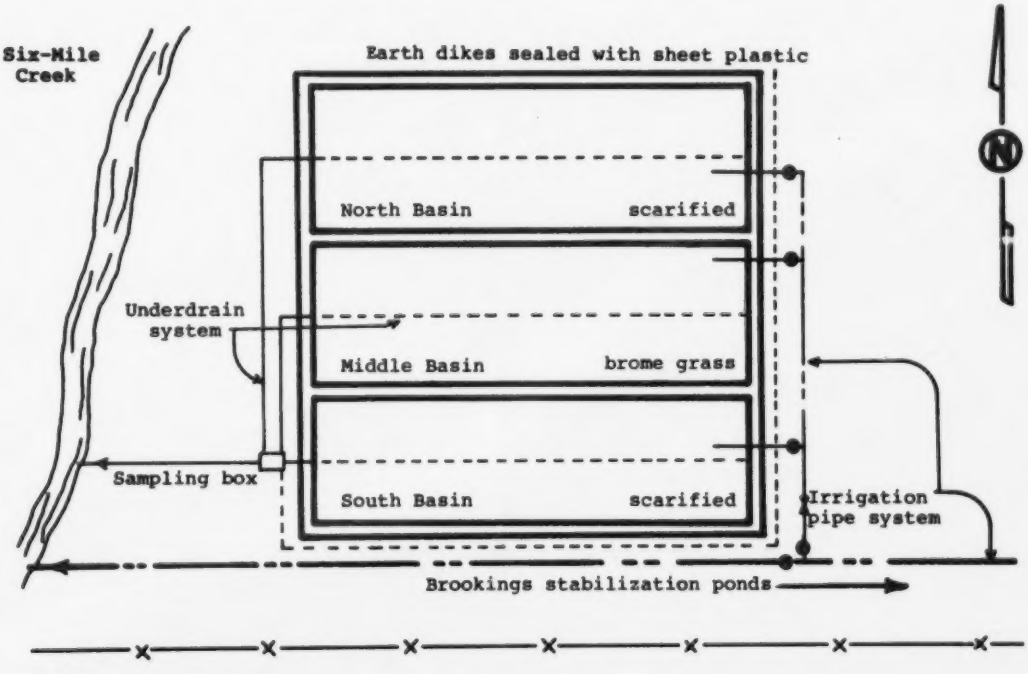


Figure 2. Layout of the pilot unit showing three basins, application system and drainage system to Six-Mile Creek as constructed in 1976.

Perforated plastic underdrains were installed under each basin at a depth of about 0.8 m (30 in) which was about 0.3 m (1 ft) above the natural ground water level at the time of construction. A perforated drain was also installed around the perimeter of the pilot unit to minimize interception of the native groundwater with basin effluent and to control the expected ground water mound. A commercial trencher cut the trenches to depth and the plastic drains were surrounded with sand and gravel. The backfill, consisting of excavated material, was tamped with an air-impact compactor. Unperforated plastic pipe was used to connect the underdrains to a wooden sampling box constructed with sufficient depth to allow freefall drainage for sample collection. Common household sump pumps were used to pump the effluent to the nearby creek.

To apply wastewater, a large steel funnel intercepted stabilization pond effluent in the overflow manhole and conducted it through a 20 cm (8 in) aluminum irrigation pipe to the pilot units. A system of 15 cm (6 in) irrigation pipes, valves, tees and elbows made possible the inundation of the basins with a by-pass line to the creek (Figure 2). A magnetic-drive irrigation meter recorded the flow to the units. Float recorders monitored water-surface elevation in each basin to allow computation of infiltration rates. A detailed description of the initial construction of the pilot unit has been provided by Voogt (2).

Operation of the pilot basins during the summers of 1975 and 1976 involved once-per-week inundation of the pilot units with stabilization pond effluent. The south and middle basins were flooded weekly with a volume equivalent to 0.6 m (24 in) application while the north basins received 0.4 m (18 in) of wastewater per week. Infiltration rates were measured during each flooding. The response of the groundwater table in the area was monitored via numerous piezometers and several wells installed in the area. Evidence of short-circuiting of wastewater directly to the drains in the fall of 1975 prompted compaction of the soil directly over the drains in the spring of 1976. A thin layer of clay was also added to the compacted area to prevent rapid infiltration in the immediate area of the drains.

In 1977 a second, deeper underdrain system was installed in the basins at a depth of about 1.3 m (4.5 ft) in an effort to improve the nitrogen removal capability of the unit. Both underdrain systems were connected to a new, deeper sampling box. After the trenches were backfilled and compacted, each surface, including the middle basin, was rototilled. Borgstadt (8) described the 1977 construction in greater detail.

In 1977, all three basins received a weekly total of 0.6 m (2 ft) of wastewater. However, instead of one flooding per week, 0.2 m (8 in) of water was applied to the basins each Monday, Wednesday and Friday. In 1978, the basins were operated much the same as in 1977. After spring rototilling, three-per-week wastewater applications began on May 24 although flooding could have occurred earlier. Variable quantities of wastewater were applied to the basins depending to some extent upon the infiltration rate. During 1977 and 1978 infiltration rates were calculated from periodic staff gage readings. Up to 0.9 m (3 ft) per week were added to the middle basin while 0.3 m to 0.6 m (1 ft to 2 ft) per week were added to the north and south basins.

During this investigation, infiltration rates were calculated only during the drainage portion of the percolation cycle, i.e. the time period after inflow to the basin had been shut off and the water level had begun to drop. During the first two years, the stage recorder charts were utilized to calculate infiltration rates by dividing the maximum depth of wastewater attained on the basin by the time for the basin to empty (usually less than 24 hours). In 1977 and 1978, more frequent wastewater applications kept the soil in the basins wet almost continually (except the middle basin) and staff gages were read periodically to compute infiltration rates.

Figure 3 provides some views of the construction and operation of the pilot facilities during the inital year. As a result of construction and changes in operation, circumstances influencing the sampling period, the annual loading rates and the treatment achieved varied from year to year. Table 1 summarizes some of the pertinent operating circumstances during the four-year period.

Individual grab samples of stabilization pond effluent were collected when each basin was flooded. During 1975 and 1976, samples from the under drains were also collected upon initiation of flow from the drains (usually about two hours after flooding started) and approximately every four hours thereafter. Usually three to five samples were collected from each basin drain before flow ceased. These samples were composited on an equal-amount basins for analyses. Grab samples were stored at 4°C until the next day to prevent physical and bacterial decomposition. The periods of weekly sampling are included in Table 1.

In 1977 and 1978, samples were collected on only one day per week from both sets of underlying drains for each of the infiltration basins. The upper drains were the same drains that had been sampled in previous years. About five grab samples collected over an 18-hour period were usually composited in equal portions to form the sample used for the analyses. The laboratory determinations performed in 1977 on the composite samples were the same as in past years although dissolved oxygen was also determined on a number of grab samples collected in 1977 and 1978.

Automatic methods employing a Technicon Auto Analyzer were used to measure kjeldahl, NH_3 and NO_3-N as well as ortho and total phosphorus. BOD_5, SS, pH and conductivity were measured according to Standard Methods for the Examination of Water and Wastewater (14). The duplicate dilution method was employed for the BOD_5 test. The glass filter method at 103°C was used for SS. Conductivity was measured at 25°C and pH determinations were made with a glass electrode pH meter standardized with a 6.86 buffer at 25°C. In 1978, additional data on inorganic chemical quality including total hardness, sodium, chlorides, alkalinity and total residue were determined according to Standard Methods for the Examination of Water and Wastewater (14). The dissolved oxygen was measured at the pilot unit site using a YSI Model 57 Oxygen Meter (Yellow Springs, Ohio).

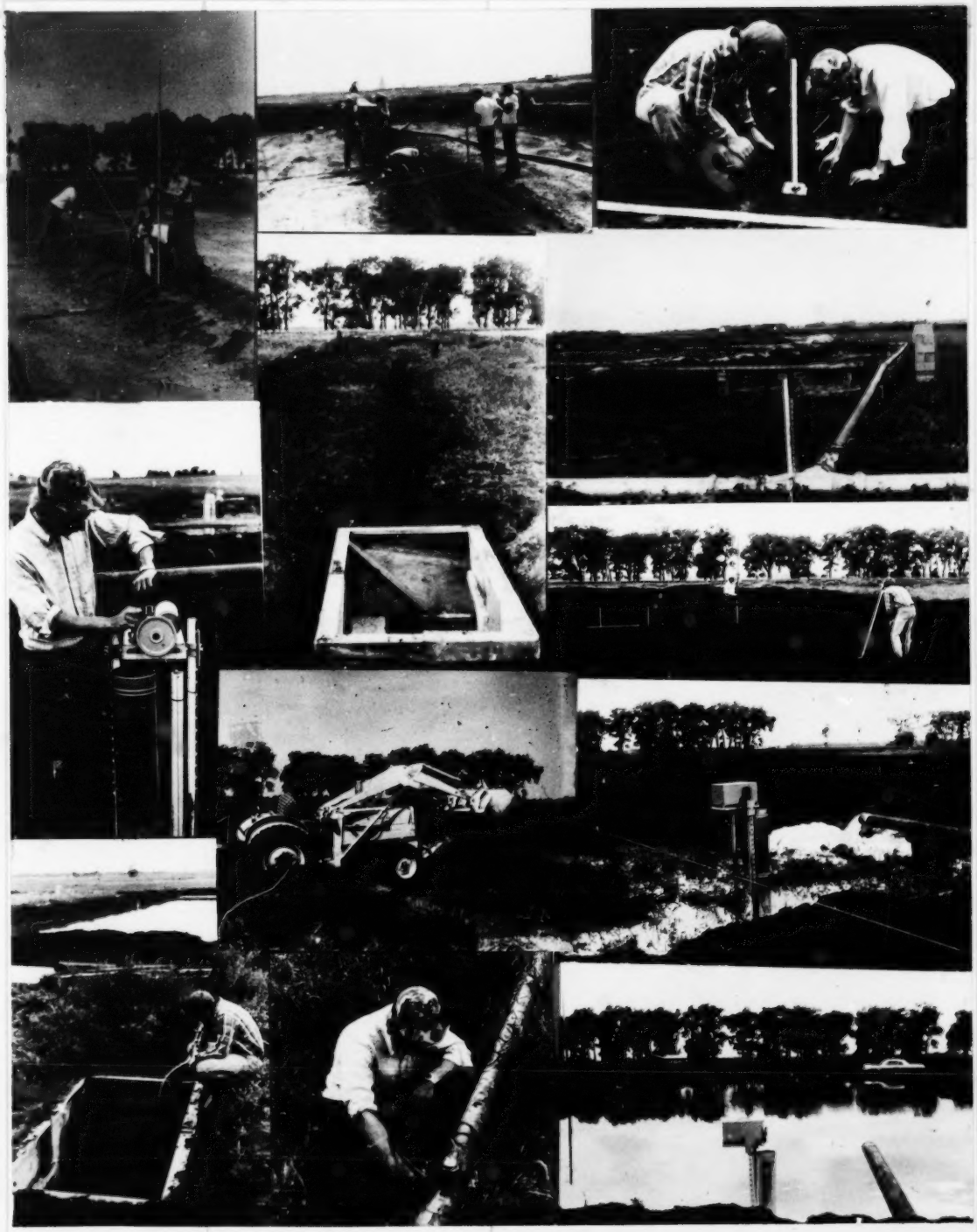


Figure 3. Construction and operation of pilot unit.

TABLE 1. SUMMARY OF OPERATING CIRCUMSTANCES INFILTRATION-PERCOLATION PILOT UNITS

Circumstances	1975	1976	1977	1978
Sampling period	June 11-December 16	May 26-November 22	July 20-October 12	May 24-November 15
Preparation of basins in spring	North and south basins cultivated & rototilled, middle basin was undisturbed.	Compacted over drain ditches. Clay layer compacted over north & south drains, remaining rototilled.	Deeper drains installed in basins All basins rototilled including middle basin.	Leveling-particularly middle basin. Rototilled during July 19 Aug. 9 rest period.
Vegetal cover conditions	Lush alfalfa & brome grass on middle basin.North & south basins mostly covered with weeds by fall.	Very heavy growth on all basins after July. Native weeds covered north and south basins, brome & weeds in middle.	Sparce growth by fall on middle basin after rototilling in July. Other basins essentially without cover.	No vegetal cover on north & south basins through operating period. Sparce cover on middle basins by late fall.
Wastewater application cycle	One day per week with about 6 days rest.	One day per week with about 6 days rest.	Every Monday, Wednesday and Friday, wet continuously.	Every Monday, Wednesday and Friday, wet continuously.
Application rate	0.6 m/application to middle and south basins. 0.45 m/application to north basins.	Same as 1975.	0.2 m/application, 0.6 m/ week for each basin.	Variable/application. Average of 0.43 m/week for north and south 0.8 m for middle.
Total wastewater applied during operation period	9.8 m to north basin & 13.3 m to middle and south basins.	13 m to north basin 17.7 m to middle & south basins.	7.8 m to each basin in a 13-week period.	About 9.3 m to north & south basins and 17.4 m to middle basin.
Rainfall during operating period	313 mm (12.3 in)	191 mm(7.5 in)	300 mm(11.8 in)	372 mm (14.7 in)
Approximate depth to ground water	June 15 - 1.10 m Sept.15 - 1.40 m	June 15 - 1.32 m Sept.15 - 1.45 m	June 15 - ---- Sept.15 - 1.20 m	June 15 - 0.95 m Sept.15 - 1.40 m
Special studies	Continuous inundation Oct.14-21, (about 3.6 m applied in 8 days) winter operation.	Spring application April 6, Winter operation.	Spring applications April 5-19	Extended rest period July 19 - August 9.

SECTION 5

INFILTRATION RATES

Sufficient infiltration rate to make rapid infiltration a practical treatment alternative for the area was of major concern. Silty clay loam soils are not generally considered suitable for rapid-infiltration land treatment and lysimeter studies (15) using similar compacted soil had demonstrated that infiltration rate was probably a limiting factor. Consequently, considerable effort was devoted to evaluating factors that might influence the infiltration rates at the pilot site.

The infiltration rates as determined over four years of operation are shown in Table 2. The trend toward decreased infiltration rates for each of the first three consecutive seasons of operation is probably the result of several factors including changes in pilot unit operation. During the 1975 season, especially in the fall period, it became evident that wastewater was short-circuiting to the drains. Algae was noted in the effluent and a correlation between influent and effluent quality was apparent.

TABLE 2. MEAN INFILTRATION RATES DETERMINED WHILE THE PILOT BASINS WERE INUNDATED WITH STABILIZATION POND EFFLUENT

Basin	Infiltration rate (mm/hour)*			
	Maximum	Minimum	Median	Mean
North				
1975	28	14	20	20
1976	20	7	16	15
1977	6	2	4	4
1978	9	1	3	4
Middle				
1975	35	27	31	31
1976	43	24	35	34
1977	23	13	19	19
1978	30	15	22	22
South				
1975	24	14	18	18
1976	17	6	12	11
1977	5	2	4	4
1978	6	1	3	4

*mm/hour x 0.039 = in/hour.

In the spring of 1976, the area over the trench was compacted, filled with clay and compacted again to prevent applied wastewater from flowing directly to the drains. The remainder of the surface of the north and south basins was cultivated and rototilled. These activities were completed sufficiently early in the spring to allow naturally selected growth to cover all three basins by mid-summer. The compaction to stop direct short-circuiting of the wastes to the drains could account for the decreased infiltration rates in 1976. The middle basin, which had very little clay added, maintained a continuous heavy plant growth in 1976 and showed greater infiltration rates.

In 1977 and 1978, operation of the pilot units with almost continuous inundation was aimed at reducing infiltration rates to promote longer contact of the wastewater with the soil and thus enhance treatment. Also the native growth of the middle basin was destroyed by rototilling after installation of the deeper drains. A continued wet surface resulting from application of wastewater about every two days was probably largely responsible for the reduced infiltration rates during the 1977 season. The reduced plant growth in the middle basin after rototilling would also be a major factor. During 1978 with similar operation, particularly the three-per-week floodings, infiltration rates were very similar to those of 1977.

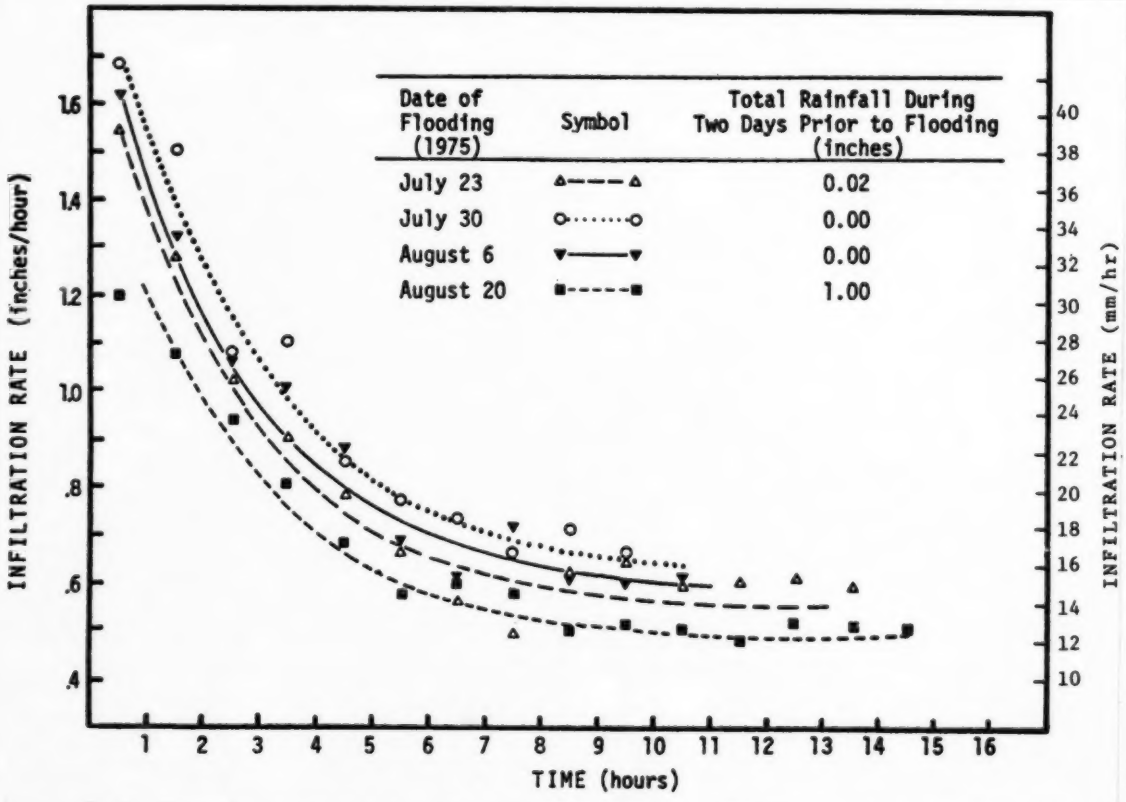


Figure 4. Hourly variation in infiltration rate of the south basin after inflow had been discontinued.

Climatic conditions were found to greatly influence infiltration rates. In 1975 weekly variation in infiltration rates for all three basins was attributed to the variable antecendent moisture content of the soil immediately prior to flooding (2). Substantial rainfall on the day prior to wastewater application noticeably reduced the infiltration rate. Because infiltration rates were computed from continuous water level records after complete inundation of the basins, hourly infiltration rates could be determined (Figure 4). The typical variation of infiltration rate with time of inundation was noted, with lower rates occurring after appreciable rainfall. Short-time minimum infiltration rates were about 12.7 mm/hour (0.5 in/hour).

During October 14-21, 1975, stabilization pond effluent was applied to the pilot unit on a daily basis to saturate the soil profile, reduce infiltration rates and improve treatment. During the eight day period, a total of 3.6 m (12 ft) of wastewater was required to keep the basins continuously inundated. With the pumps stopped, the drains below the basins were inactived and the piezometric groundwater table rose to within 23 cm (9 in) of the basin surfaces. Daily measurements revealed that mean infiltration rates after the first day of continuous flooding were 15.5, 14.5 and 12.7 mm/hour (0.61, 0.57 and 0,50 in/hour) for north, middle and south basins respectively. Almost uniform infiltration rates after the first day suggested an equilibrium infiltration rate of about 12.7 mm/hour (0.5 in/hour) for the basins. The highly vegetated middle basin showed little advantage of higher rates with continuous inundation after the first two days of continuous flooding (2).

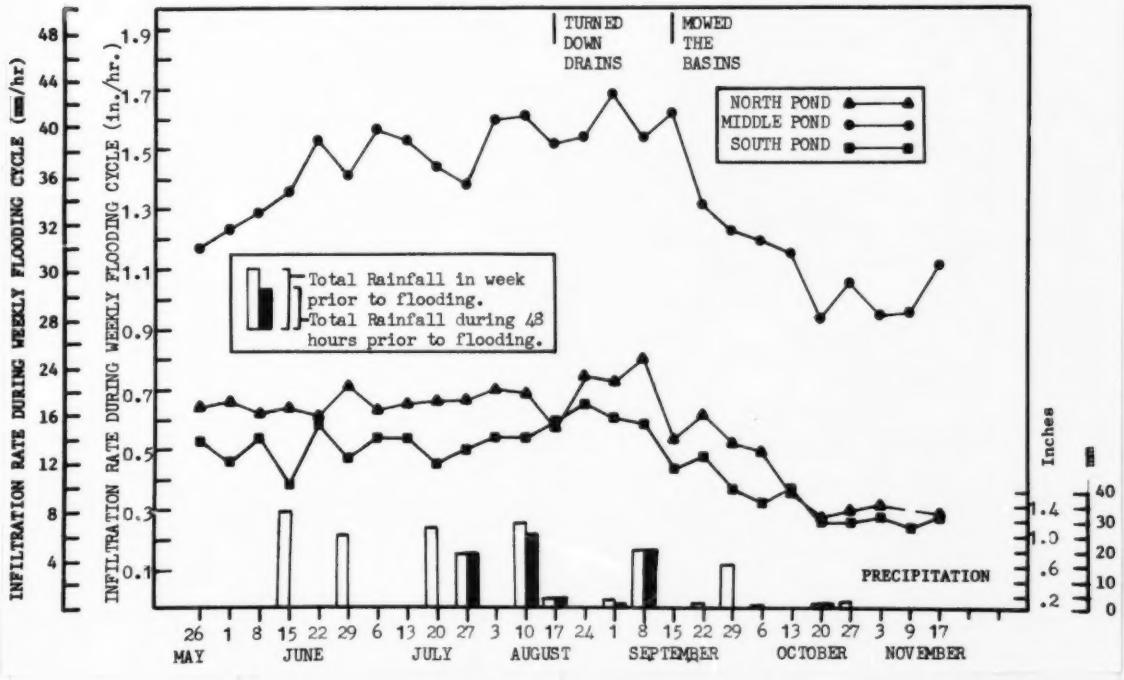


Figure 5. Infiltration rates and precipitation at the pilot unit-1976.

During the 1976 season, the area of pilot units experienced only 19 cm (7.5 in) of rainfall and evapotranspiration rates became a major influence on infiltration rates since heavy plant growth covered all three basins (5). As in 1975, infiltration rates varied considerably throughout the 1976 season (Figure 5) for all basins with much higher infiltration rates occurring in the middle basin. The infiltration rate of the south basin was shown to be significantly lower than the rate of the north basin which received 15 cm (6 in) less wastewater per week.

During the 1977 season, rainfall in the area was substantial, nearly 33 cm (13 in), but with the more frequent wastewater applications, periods of the rainfall did not appear to influence infiltration rates (Figure 6). The middle basin which drained rapidly and had developed plant regrowth after rototilling continued to have much higher infiltration rates than the other basins. Comparatively little difference in the infiltration rates between the north and south basins were noted in 1977 after loading rates were identical.

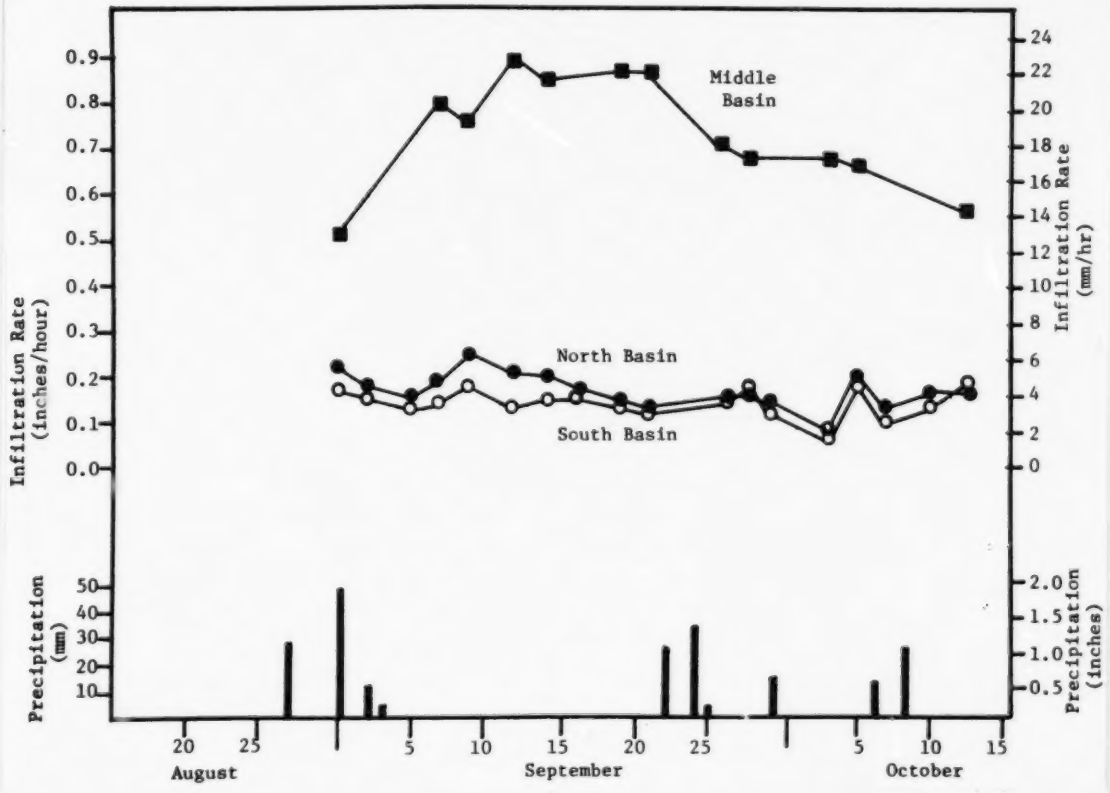


Figure 6. Infiltration rates and precipitation in 1977 when total applied wastewater was identical with three weekly applications.

SS, primarily algae in the applied stabilization pond effluent, varied considerably during all four years of the study. Studies to correlate SS and infiltration rates in 1975 and 1976, when once-per-week wastewater application were used, showed that SS in excess of 60 mg/l did not cause reduced infiltration rates (2), (5). During this period the cyclic operation provided opportunity for the surface to dry.

The loading rate was a controlled variable between the north and south basins during the 1975 and 1976 seasons. The south basin received 60 cm (24 in) of wastewater weekly and the north basin received 45 cm (18 in). The north basin was shown statistically to have a significantly greater infiltration rate for both years. However, slight variation in soil type rather than different loading rates between those basins was believed to be the reason for the difference (5). In 1977, infiltration rates between the north and south basins were quite similar with identical wastewater application rates of 60 cm/week (24 in/week) as shown in Figure 6.

Infiltration rates in 1978 were very similar to those of 1977 and it appears that an equilibrium loading condition for the soil in the area would be about 45 cm/week (18 in/week) for the scarified north and south basins. The middle basin continued to accept water readily for all four years and three weekly floodings of 60 cm (2 ft) each were applied in the late summer and fall of 1978.

The surface layer of the middle basin probably contained a much higher organic content than the other two basins because it did not have the highly organic surface layer removed during construction. For this reason alone, the middle basin would have been more likely to retain a soil structure conducive to the higher infiltration rates observed. In addition, the surface of the basin, as well as the underdrains, are about 20 cm (8 in) higher in elevation (8). Consequently, the drains in the other basins would tend to supplement the drainage of the middle basin and thus more adequately rejuvenate the infiltration rate during the drying cycle. In summary, the higher infiltration rate in the middle basin is probably the result of several factors including a more luxuriant vegetative cover, higher organic content of the soil and better subsurface drainage. Nevertheless, these studies suggest that with similar soil conditions substantially higher infiltration rates can be maintained if the basins are not scarified.

SECTION 6

GROUNDWATER RESPONSE

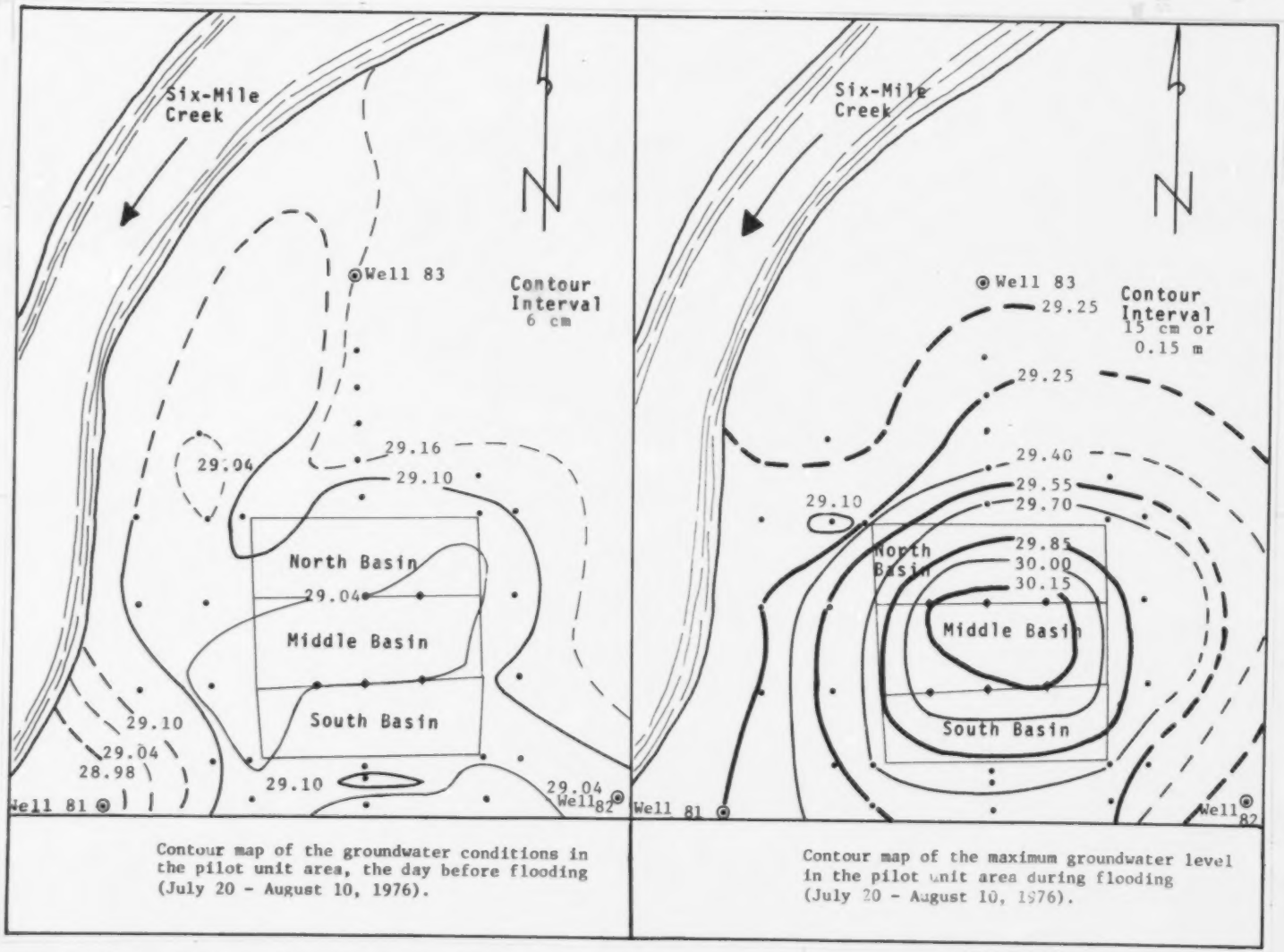
When this project was initiated, the technical review resulted in a request of a study of the response of the groundwater to the periodic basin floodings. Numerous piezometers consisting of thin-walled plastic pipe were installed for evaluating the groundwater hydraulics beneath and surrounding the pilot units. The piezometers, 1.8 m (6 ft) in length, were installed so the tops were at a common elevation to facilitate rapid measurement of the groundwater level. Although the rising water that accompanied a basin flooding carried soil into some piezometers causing clogging, periodic cleaning of the piezometers with a long metal rod allowed collection of reliable groundwater level data.

Figure 7 shows the average groundwater levels the day before flooding as well as the approximate maximum water level attained by the groundwater mound during a flooding cycle. These data represent the average conditions for a hot summer period in 1976 when weekly flooding was used. The piezometers and several well points used for continuous water level monitoring are located in the figure. Groundwater conditions the day before the weekly flooding reveal a "dishing out" phenomena mainly below the middle basins presumably as a result of the drain locations.

In 1976 the maximum groundwater mound occurred about 12 hours after the basins were flooded. The mound was found to be quite uniform and centered under the middle basin. The maximum height of the mound rose to within 15 cm (6 in) of the ground surface during a flooding cycle in the summer and to within 30 cm (1 ft) in the late fall. These results were not unexpected because the mounding effect would be greatly influenced by the comparatively high infiltration rate of the middle basin.

To illustrate the response of the groundwater under the basins during a flooding cycle, cross sections of the water level at various times before and after the weekly wastewater applications were prepared (Figure 8). Four-week averages of piezometer readings during the summer period of July 20-August 10, 1976 were selected as representative. As stated previously, the piezometers had a tendency to clog and required periodic cleaning with a rod. Thus, by averaging the data for a four-week period and eliminating data from piezometer tubes that were obviously clogged, a better estimate of the actual groundwater conditions could be obtained.

The water level represented by the 10:00 p.m. reading of the piezometers on the day of flooding is probably near the maximum groundwater height



Contour map of the groundwater conditions in the pilot unit area, the day before flooding (July 20 - August 10, 1976).

Contour map of the maximum groundwater level in the pilot unit area during flooding (July 20 - August 10, 1976).

Figure 7. Groundwater elevations at the pilot units before and during wastewater applications-1976.

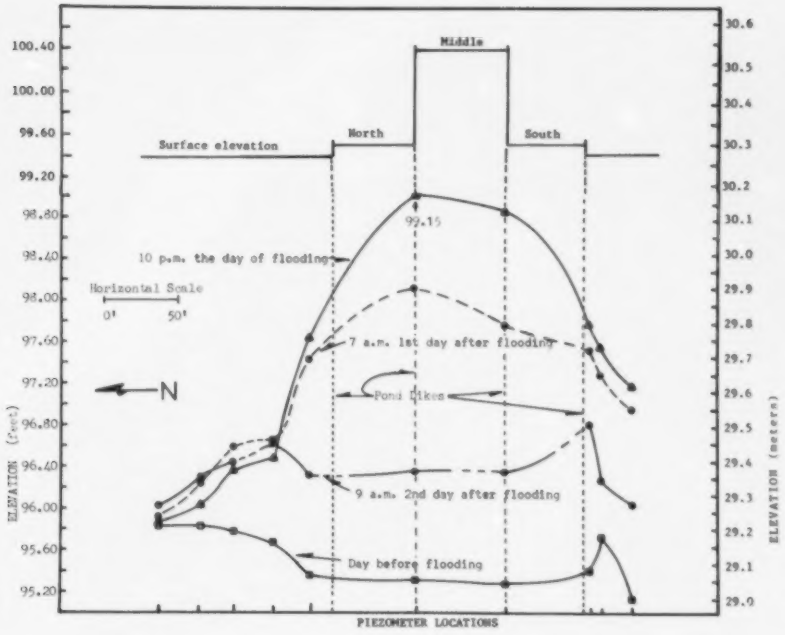


Figure 8. Groundwater elevations on a center north-south cross section of the infiltration basins at four times during a flooding cycle-1976.

following a flooding. The usual procedure of applying wastewater to the basins in a south-middle-north sequence required about 11 hours in 1976 starting about 7:00 a.m. At that time in 1976, a water depth of about 40 cm (1.3 ft) was being attained on the north and south basins when flooding was completed. Those two basins were empty about 20 to 30 hours later while the middle basin emptied in about eight hours. About two days after flooding started, the groundwater had reached near normal levels primarily because of the drains. In the remaining five days before flooding resumed, groundwater under the basins was lowered an additional 0.3 m (1 ft) to exhibit the "dished-out" profile just before the flooding cycle was repeated.

Figure 9 allows comparison of the groundwater response in 1976, when a single weekly wastewater flooding of 0.6 m (2 ft) was used, to 1977 response with three 0.2 m (8 in) applications per week. The measurements are for the piezometer located on the dike between the north and middle basins midway between the ends of the basin. The data plotted are for single floodings in mid-August in 1977 and early September, 1976 (8).

With the 0.2 m (8 in) wastewater application and lower infiltration rates in 1977, the rise of the groundwater mound was only about 50 percent of the rise in 1976. The maximum water level was also realized in much less time and recovery was more rapid in 1977. Complete recovery of the groundwater table

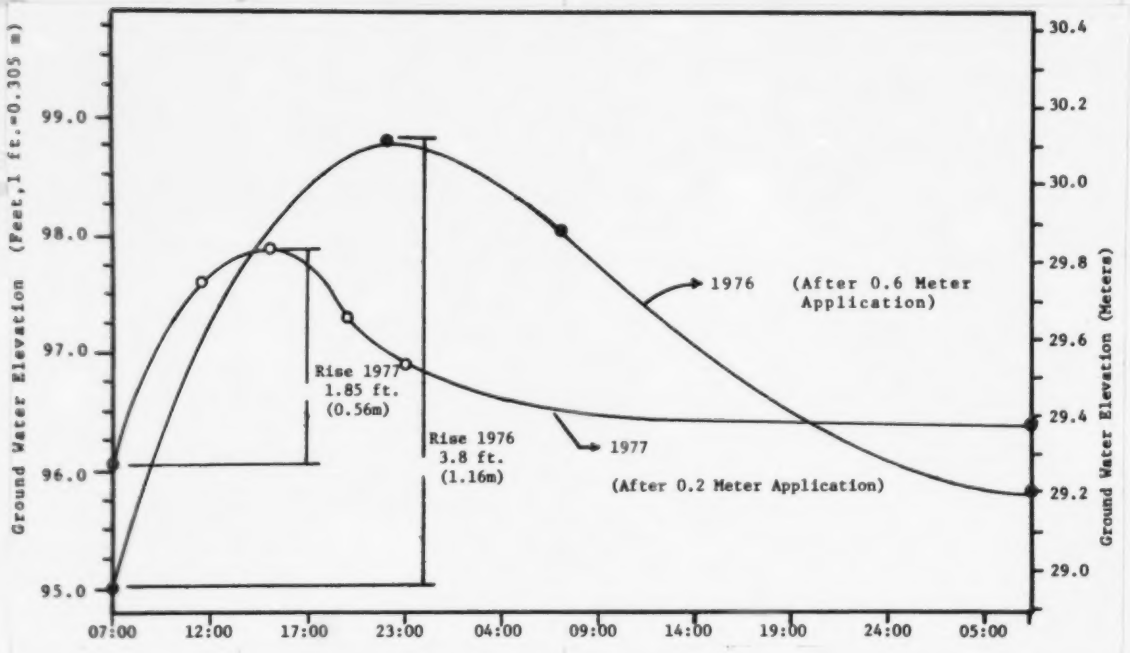


Figure 9. Groundwater elevation at a mid-basin piezometer during representative flooding cycles in 1976 and 1977 (8).

between floodings was not, however, accomplished in 1977 in a two-day period. During 1977 the groundwater level at that particular piezometer was approximately 0.3 m (1 ft) higher before flooding started. The higher water table may have been the result of more frequent inundation of the basins or the greater rainfall in 1977.

The higher groundwater mound that formed in 1976 produced a steep hydraulic gradient under the basins forcing water from the immediate area of the pilot units. This lateral movement can be observed by the raised water levels at piezometers north of the basin dikes (Figure 8). By contrast, the flatter groundwater mound in 1977 would tend to restrict lateral movement of water from the area and allow greater removals of water by the underdrain system. Although a meter was not installed, it was estimated that less then 25 percent of the renovated water was recovered by the drains and was pumped to the creek in 1976. In 1978, the metered recovery from the drainage system was about 52 percent of the applied wastewater and a higher recovery rate would have been expected in 1977 when operating conditions were similar and natural groundwater levels were higher throughout the area.

From continuous monitoring of the general groundwater elevation at well points in the area of the pilot basin, the influence of the weekly wastewater applications could also be demonstrated. As shown in Figure 10, each flooding of the basins in 1976 caused a definite rising of the water table at the

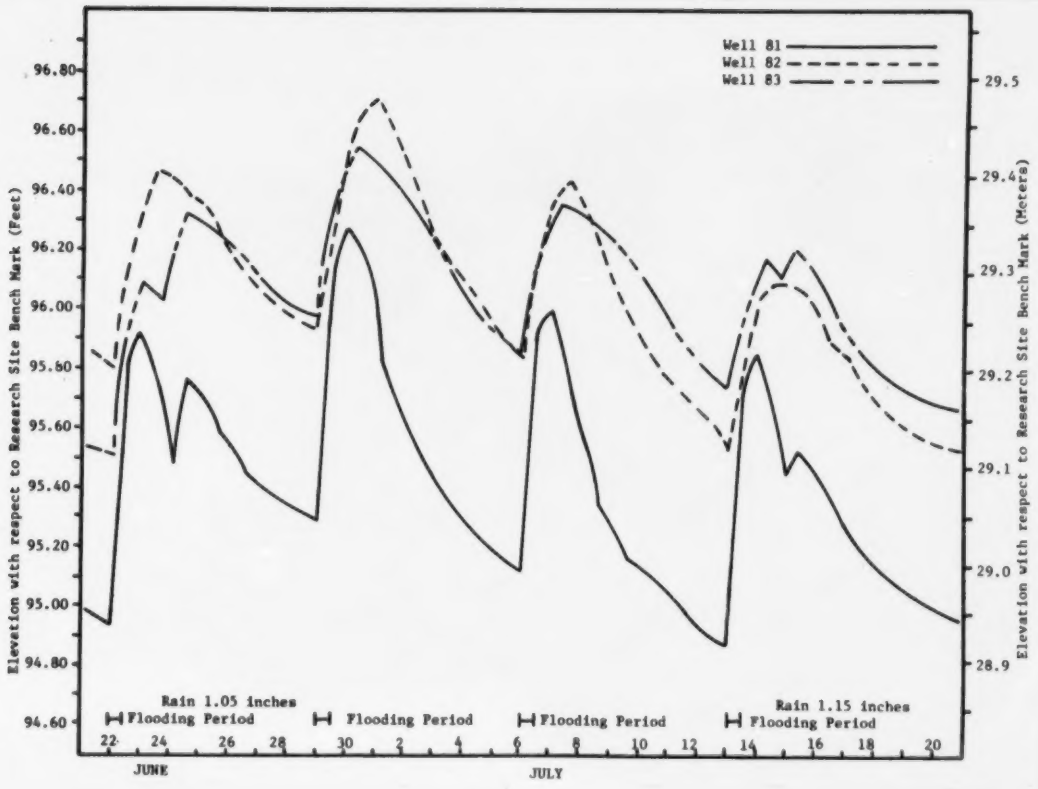


Figure 10. Changes in groundwater elevations at monitoring wells in 1976.

wells located about 30 m (100 ft) from the basins. The well located between the pilot basins and the creek (Well 81) experienced a water level increase of about 0.3 m (1 ft) with each weekly wastewater application. The breaks in the recession curve shown in the first and fourth flooding cycles are the result of substantial rainfall in the area which may also have caused substantial short-term rises in nearby Six-Mile Creek. Also the minimum water levels in succeeding cycles reflect the general lowering of the groundwater during 1976 when very little rainfall occurred.

In 1977 on several occasions, rainfall caused sharp rises in Six-Mile Creek as a result of surface runoff. By comparing water levels in the creek and the nearby wells in 1977, Borgstadt (8) demonstrated that the creek served in both influent and effluent conditions with respect to the groundwater. Thus, the creek would also serve to remove renovated water not pumped from the drains. Overall, however, the drainage system with pumping provided a satisfactory method of controlling the high water table in the treatment area particularly when frequent wastewater applications were employed.

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SECTION 7

EFFLUENT QUALITY

The analytical data obtained for periods of operation from 1975 to 1978 are summarized as mean concentrations in Table 3. It will be noted that BOD_5 and SS determinations were not performed in 1978 when additional data were collected for the inorganic constituents in the effluents. The mean values reported in Table 3 represent data for about 21, 27, 13 and 24 weekly samples in the 1975 through 1978 seasons respectively. In 1977, the quality of the influent reported for the old (upper) and new (lower) drains differed because two fewer samples were collected from the old drains. The individual quality results for the study have been presented in several thesis reports (3, 4, 6, 7, 9, 10, 11) although more complete data summaries including the number of samples and the maximum, minimum, median and mean values of the various determinations for each of the four years are included in the Appendix.

During each season, the effluent from the stabilization pond experienced wide variations in quality and short-circuiting of the wastewater to the underdrains was evident in 1975. The infiltration basins, however, produced effluents of far more uniform quality, and each successive year generally demonstrated an improved quality of effluent. With few exceptions, the quality of water from the new, deeper drains was superior to that of the upper drains. The effluent collected from the drains of the pilot unit had the appearance of groundwater. After the first year, algae was observed very infrequently in the effluent of the upper drains, and usually only from the middle drain. Little color was noted in the water and the samples did not have unusual odors.

Quality trends and variability for BOD_5 and SS appear in Figure 11 which represents data for the 1976 year when weekly flooding and only the upper drains were in use. Influent BOD_5 concentrations ranged from 4.6 mg/l to 59 mg/l while SS levels showed a spread of 15.8 mg/l to 71 mg/l during the May to November operating season in 1976. During other years, the range of extreme values was similar although the seasonal quality changes were quite different. SS in the influent consisted largely of algae, including the Chlorella and Scenedesmus species, and daphnia (6, 7). The trend toward poorer effluent quality from the drains in the fall of 1976 was not directly attributed to mowing the basins but rather to lower temperatures and higher levels of pollutants in the influent during that period.

BOD_5 and SS concentrations in the basin effluents during the initial two years were generally somewhat higher than anticipated. Since the upper drain

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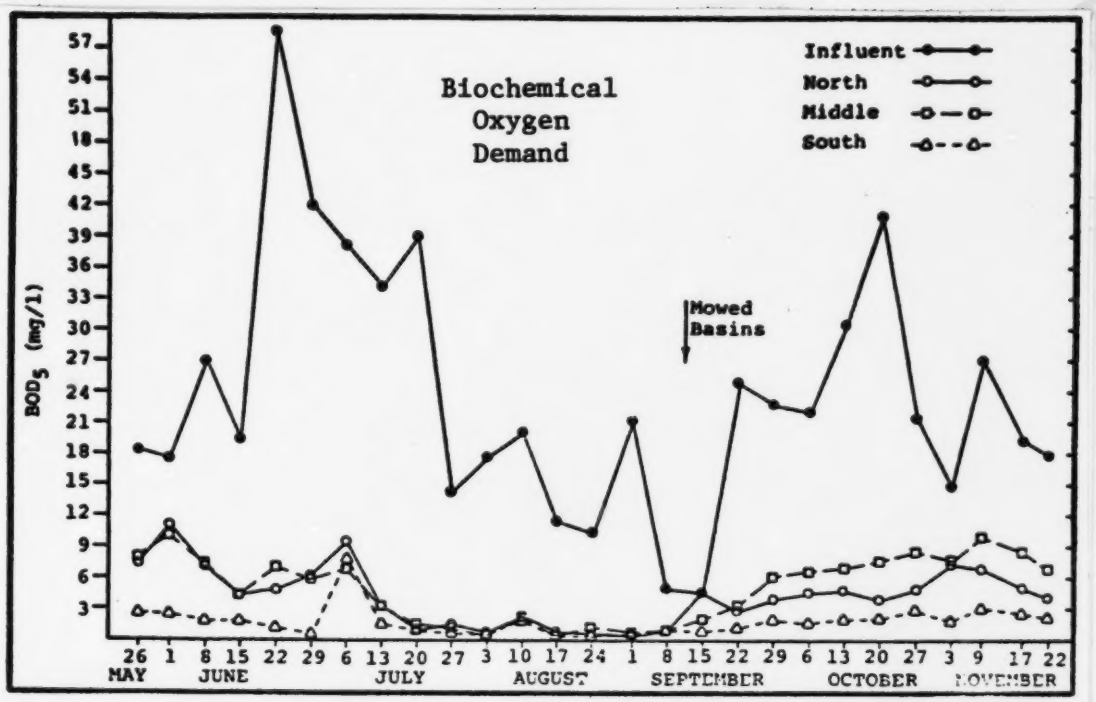
TABLE 3. MEAN QUALITY OF INFLUENT AND RENOVATED WATER FROM DRAINS

Determination	Mean concentration-mg/l							
	Influent		North		Middle		South	
	Old	New*	Old	New	Old	New	Old	New
BOD_5								
1975	29	----	8.9	----	11	----	6.8	----
1976	24	----	4.3	----	5.1	----	1.8	----
1977	23	21	3.2	1.1	4.6	1.7	2.9	1.2
Suspended Solids								
1975	44	----	7.0	----	9.7	----	5.8	----
1976	38	----	4.0	----	5.8	----	2.3	----
1977	24	27	4.1	1.9	8.2	2.4	1.9	1.7
Conductivity (umho/cm)								
1975	1600	----	1800	----	1800	----	1800	----
1976	1800	----	2000	----	1900	----	2200	----
1977	1900	1900	2100	2000	1900	2100	2000	2000
1978	1900	----	2100	2000	1900	2000	2100	1900
Ortho-Phosphorus								
1975	3.4	----	1.7	----	1.8	----	1.4	----
1976	2.6	----	1.4	----	1.3	----	1.2	----
1977	3.0	3.0	1.3	0.24	1.9	0.47	0.88	0.25
1978	----	2.6	0.7	0.21	2.0	0.38	0.46	0.27
Total Phosphorus								
1975	4.2	----	2.1	----	2.3	----	1.7	----
1976	3.5	----	1.6	----	1.5	----	1.1	----
1977	3.2	3.5	1.5	0.40	2.2	0.61	0.98	0.32
1978	----	3.4	0.74	0.24	2.2	0.41	0.58	0.30
Ammonia Nitrogen								
1975	10.5	----	3.6	----	3.3	----	2.3	----
1976	7.0	----	1.4	----	1.4	----	0.63	----
1977	11.5	10.6	1.0	0.62	2.2	0.75	0.60	0.86
1978	----	10.2	0.34	0.85	3.2	0.36	1.0	1.2
Nitrate Nitrogen								
1975	1.4	----	8.8	----	7.7	----	11.1	----
1976	0.59	----	5.8	----	7.0	----	9.9	----
1977	0.47	0.45	1.6	1.4	5.7	6.3	2.0	1.9
1978	----	1.0	1.6	0.64	3.9	2.0	0.92	0.89
Total Kjeldahl Nitrogen								
1975	13	----	4.2	----	4.7	----	2.9	----
1976	10	----	2.6	----	2.8	----	1.4	----
1977	13	12.5	1.8	1.3	3.2	1.4	1.3	1.5
1978	----	13.0	0.77	1.2	4.2	0.78	1.4	1.4
pH (units)			(median values)					
1976	8.3	----	7.2	----	7.3	----	7.2	----
1977	8.0	8.0	7.4	7.5	7.4	7.5	7.5	7.5
1978	7.9	7.9	7.4	7.3	7.4	7.3	7.4	7.4

*Old drains are upper drains installed in 1974 while new drains are lower drains installed in 1977.



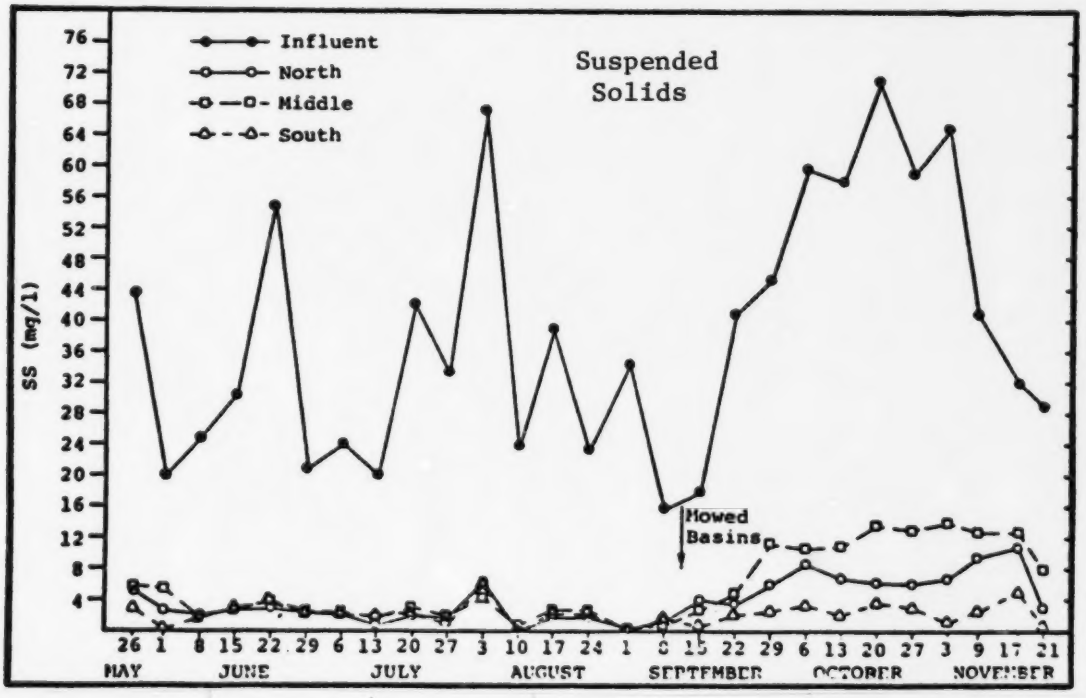


Figure 11. Variation of BOD_5 and SS for influent and drain effluents during 1976.

lines were located only about 0.8 m (30 in) below the surface, the samples were collected from water that was representative of that contained in the recharge mound below the basins. Consequently, it is unlikely that the wastewater was provided sufficient detention time in the soil matrix for maximum treatment. Certainly, the sampling situation was not comparable to samples collected from wells tapping continuously saturated soils where approach velocities would be much lower and available soil contact time much longer. The "new" drains were installed at a greater depth in 1977 and the effluent quality from these drains was much improved with respect to BOD_5 and SS at the low levels expected.

Increases in conductivity of about ten percent were noted in the drain effluents throughout the study. The inorganic chemical data collected in 1978 (see Appendix) suggest that calcium carbonate was leached from the highly calcareous soil and a new equilibrium would need to be established between the soil-water system. Substantial increases in hardness and alkalinity were noted in the drain effluents in 1978. As would be expected, the soil system and the associated biological action served to modify the extreme pH values (often above pH of 8.5) discharged from the stabilization pond. The effluent from the drains usually had a pH of 7.2 to 7.6.

Chlorides data collected in 1978 suggest that relatively little dilution with native groundwater was occurring in 1978. Sodium levels also showed little difference between influent and effluent samples although with the nature of the soil in the area a change might be expected. For the rather highly mineralized effluents, a factor of 0.69 when applied to the conductivity values in umho/cm would closely approximate the total residue on evaporation in milligrams/liter.

The analytical data demonstrate that phosphorus was removed to some extent but not nearly to the degree expected. Only about 50 percent of the ortho and total phosphorus was removed by the pilot infiltration basins. Effluent phosphorus concentrations in the upper drains frequently exceeded 1.0 mg/l and these concentrations would probably not be acceptable where stringent limits of phosphorus were stipulated for a treated wastewater discharge. Substantially lower concentrations of phosphorus were noted in the effluent from the deeper drains in 1977 and 1978.

Based upon the results of lysimeter studies (15) with disturbed soils, excellent phosphorus removals were anticipated. As explained previously, short-circuiting of wastewaters to the drains and general lack of contact time with the soil were probably contributing factors to the less efficient phosphorus removals. With the silty clay loam soil, the unusually high infiltration rates in the early years of operation suggest that the soils in the area may be characterized by peds and subsurface desiccation cracks. Certainly the possibility exists that underdrained, undisturbed soil systems similar to the middle basin may not provide the adsorption and removals of phosphorus that might be expected from laboratory studies with lysimeters and soil columns using disturbed soil samples. Careful attention to placement of drains might improve effluent quality. For example, drains could be placed under dikes and at greater depths to prevent short-circuiting. The deeper drains collecting water from saturated soils provided renovated water with less than 1.0 mg/l of phosphorus continuously.

During the 1975 season, fecal coliform determinations were performed on individual grab samples of the influent and the three basin drain effluents. The most probable number (MPN) of fecal coliforms per 100ml was determined by the EC medium method described in Standard Methods for the Examination of Water and Wastewater (14). The logarithmic mean concentration of coliform organisms of the applied water was 1443/100 ml in 1975 and was reduced only 44 percent by the north and middle basins and 77 percent by the south basin (3).

TABLE 4. FECAL COLIFORM RESULTS BY MEMBRANE FILTER TECHNIQUE-1976

	Fecal coliforms/100ml				
Date	Influent	North	Middle	South	Peripheral drain
July					
13-14		3	7	1	2
20-21		2	4	1	1
27-28		300	44	50	2
August					
3-4		11	114	265	202
10-11		39	20	22	15
17-18	129	9	6	16	9
24-25	948	191	171	90	52
September					
1-2	314	105	193	77	4
8-9	272	128	198	122	1
16-17	1200	340	1135	269	18
22-23	2864	1408	760	37	2
29-30	3120	728	252	46	1
October					
6-7	3020	1671	1795	93	1
13-14	6120	691	1343	81	1
20-21	14420	2383	4414	338	
27-28	12040	1584	3268	91	
November					
3-4	1000	113	113	11	
9-10	4000	348	96	40	
17-18	4900	1863	2894	152	
21-23	4000	165	1773	93	
Logarithmic Mean	1980	168	215	47	
Removal Efficiency		91.5	89.1	97.6	

These coliform data in 1975 were very difficult to interpret for individual floodings because on numerous occasions the reported fecal coliform densities of the drain effluent samples exceeded those of the influent sample. The probable short circuiting of the applied wastewater to the shallow drains was one explanation of the high effluent coliform concentrations. Visual evidence of numerous higher life forms (protozoa and daphnia) in the influent samples also suggested that these organisms were grazing on the bacteria in the stabilization pond effluent samples before the analyses could be performed. For these reasons, special attention was given to obtaining fecal

coliform densities in 1976.

Table 4 contains a summary of the fecal coliform organism determinations performed in 1976. On each flooding date, three to five grab samples were collected from each sampling point and were counted separately employing the membrane filter technique. The geometric mean value determined from the results of the individual grab samples was then reported. From the summary fecal coliform results, it appeared that effluents from the peripheral drain, the south, and possibly the north, infiltration-percolation basins would have met many effluent limitations for fecal coliforms depending upon the specific criteria. The middle basin, where effluent fecal coliform concentrations were frequently higher, may have still been subject to some short-circuiting effect through the drain trench or through the undisturbed soil above. In 1977, only a few fecal coliform determinations were made for the deeper drains and all were very low.

To demonstrate the excellent treatment capability of the infiltration system, the water quality of the effluent from both drain systems was compared to several possible effluent standards. The determinations and the limiting standards selected and the percent of samples that were in compliance with the standards are shown in Table 5. Because BOD_5 and SS data were not collected for 1978, the data evaluated were for 1976 when weekly flooding was used and 1977 when wastewater was applied three times per week. Results for 1978 were of equal or better quality compared to those in 1977.

From Table 5 it can be observed that an effluent standard of 8 mg/1 for BOD_5 and SS was met 100 percent of the time by the effluent from the deeper drains. Phosphorus removals to 1.0 mg/1 concentration was also accomplished consistantly by the effluent from the deeper drains. The pH range of 6.3 to 9.0, although occasionally violated by the stabilization pond effluent (influent), was met at all times by the land system effluent. Compliance with NH_3 and NO_3 standards is discussed in the following section. A potential dissolved oxygen (DO), requirement was the only standard that the effluent from the pilot unit was not able to satisfy with consistency after 1977.

In summary, effluent quality from the deep drains of the pilot basin during 1977 and 1978 easily met most discharge standard for BOD_5, SS, phosphorus and pH. Limited fecal coliform data collected in 1977 indicate that a standard of 200 fecal coliforms per 100 ml would also be met without disinfection. If, however, the discharge standard included a DO concentration, the effluent would violate this limit. Some form of supplemental aeration could probably be included into the design of a drained and pumped system as would be required with a site with a high water table similar to that of the pilot unit.

TABLE 5. COMPLIANCE OF WATER QUALITY WITH POTENTIAL DISCHARGE STANDARDS

Parameter	Limiting standard mg/l	Percent of samples meeting standard: Influent 76 old[1]	Influent 77 old	Influent 77 new	North 76 old	North 77 old	North 77 new	Middle 76 old	Middle 77 old	Middle 77 new	South 76 old	South 77 old	South 77 new
BOD_5	2	0	0	0	27	27	92	27	9	69	65	50	92
	4	0	0	0	46	64	100	42	36	100	96	73	100
	8	6	18	20	87	100	100	100	100	100	100	100	100
SS	2	0	0	0	31	27	62	19	10	62	38	78	62
	4	0	0	18	62	64	92	54	30	92	92	88	100
	8	0	0	15	88	91	100	69	60	92	100	100	100
Total Phosphorus	0.5	0	0	0	0	0	77	0	0	54	0	0	92
	1.0	0	0	0	4	25	92	7	0	92	33	55	100
pH (units)	6.3-9.0	88	100	100	100	100	100	100	100	100	100	100	100
DO	4.0	--	--	--	--	12	0	--	12	0	--	0	0
	6.0	--	--	--	--	0	0	--	0	0	--	0	0

[1]Old drains are upper drains installed in 1974 and new drains are lower drains installed in 1977.

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SECTION 8

NITROGEN CONTROL

When the project was initiated, the major nitrogen concern was for NH_3-N concentration. With a high water table situation, renovated water would be collected and pumped to a surface water stream. Effluent limits of NH_3-N were the result of a continuous 1.0 mg/1 or less in-stream allowable concentration for fish propagation waters. In South Dakota, virtually all streams are classified fish propagation waters. In 1977, the stream standard was changed to 0.02 and 0.04 mg/1 un-ionized NH_3 which requires pH and temperature data to measure compliance. Since most South Dakota streams flow intermittently, the effluent permits for NH_3 have stipulated very low concentrations, 1.5 mg/1 for Brookings in 1976. Oxidation of the NH_3-N to NO_3-N appeared to be an acceptable solution to the NH_3 limitations since discharge of treated wastewater to lakes is not permitted in South Dakota.

The concentration of NO_3 in the effluent from the pilot basins became a second concern of the study. Although the shallow water table made possible the collection of renovated water and discharge to the nearby stream, it soon became apparent that only a portion of renovated water was pumped to the stream. High concentrations of NO_3 could become a quality threat to drinking water supplies, particularly when similar large facilities are less suitably located with respect to major aquifers. Consequently, NH_3 and NO_3 concentrations were of concern in the effluent from the infiltration basins. Control of both of these nitrogen forms led to a desire to accomplish total nitrogen removal.

Figure 12 shows the mean nitrogen concentrations for influent (stabilization pond effluent) and the north, middle and south drain effluents from the pilot unit for the period from 1975 through 1978. The relative concentrations of NH_3 , NO_3 and organic nitrogen are also shown. Several important observations can be made from these data.

The concentration of NH_3-N of the stabilization pond effluent (influent to the pilot unit) comprised the major fraction of the total nitrogen and was far in excess of the 1.5 mg/1 allowable NH_3-N standard. In the basin drain effluents, NH_3-N concentrations were frequently reduced to below the 1.5 mg/1 limit particularly after 1975 when direct short-circuiting to the drains was evident. In 1977 when three wastewater applications per week provided the weekly loading, NH_3-N was consistently reduced to below 1.5 mg/1 in the lower drains. From the upper drains, particularly from the middle basin,

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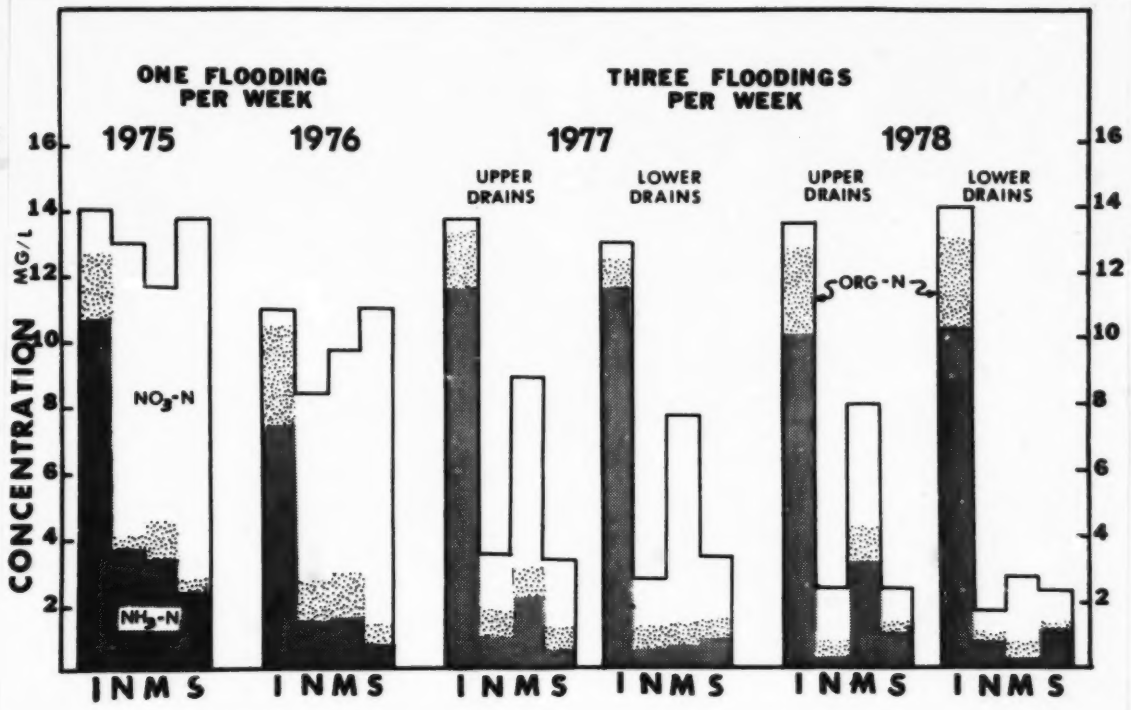

Figure 12. Annual mean nitrogen concentrations for influent(I), north(N), middle(M) and south(S) drain effluents for infiltration basins, 1975-1978,(11).

this limit was still frequently exceeded. With the pH of the effluent about 7.5 and temperature about 18°C, meeting the limits for un-ionized ammonia was virtually assured.

From Figure 12, it can also be observed that the total nitrogen discharged from the pilot basins was almost identical to that of the influent in 1975 and 1976. During these years with once-per-week wastewater applications, increases in NO_3 accounted for the reductions of NH_3. By contrast, in 1977 and 1978 when more frequent wastewater applications prevented effective aeration of the soil, NO_3 and total nitrogen in the drain effluents were reduced significantly. The exceptions were the effluents from the middle basin where a much higher infiltration rate resulted in intermittent drying and aeration of that basin.

A rather wide range of concentrations of the various nitrogen forms was noted throughout each of the four years of operation. For the stabilization pond effluent (influent), NH_3-N usually was the major component with substantial concentrations of organic nitrogen and comparatively small quantities of NO_3. NO_3-N was predominant in the drain effluents followed by NH_3 and

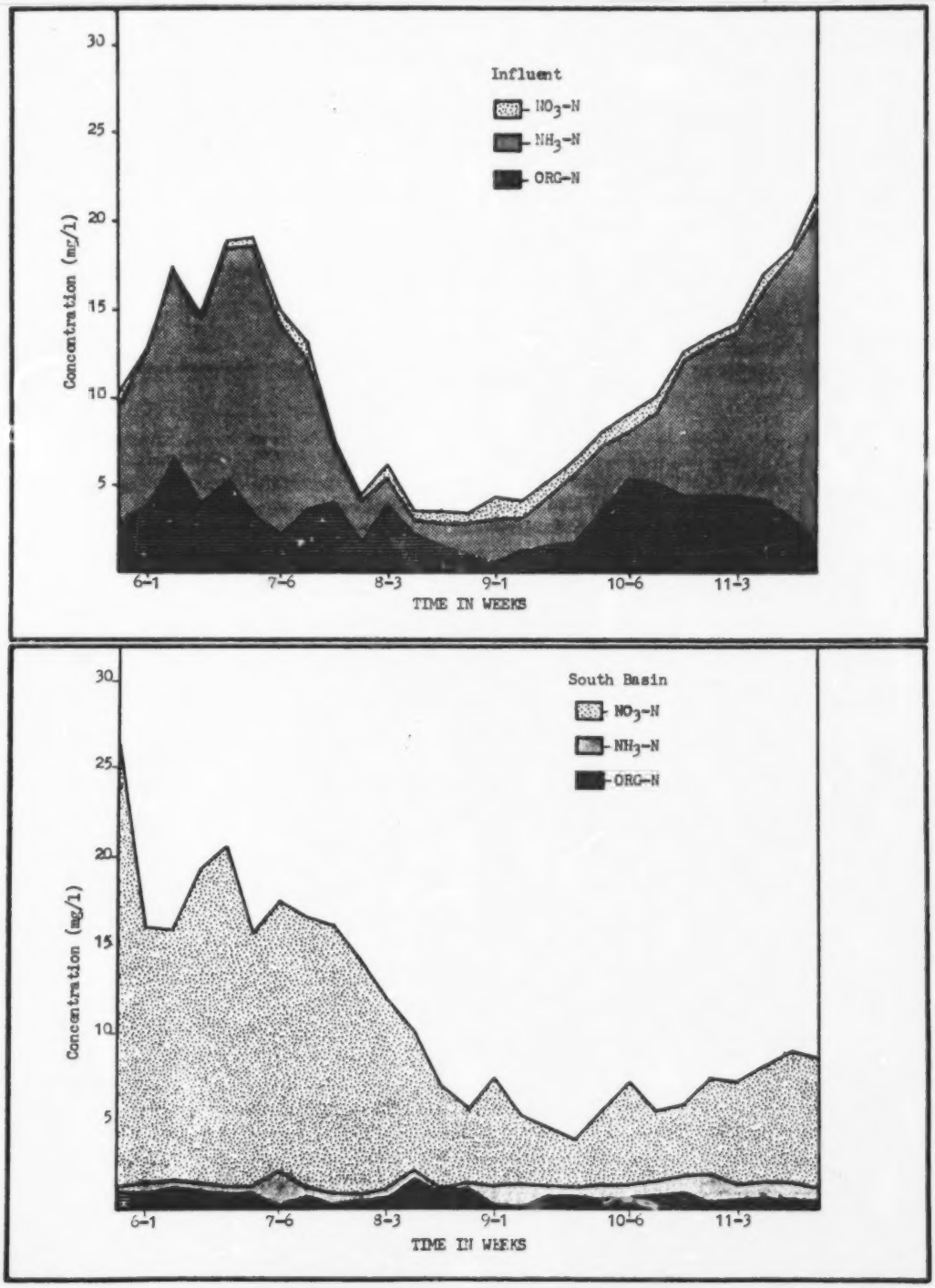

Figure 13. Variation of nitrogen forms in the influent and drain effluent of the south basin in 1976 (6).

organic-N. Figure 13 compares the nitrogen forms in the influent and south drain effluent in 1976.

During the 1976 season with only one flooding per week, the south basin (Figure 13) actually discharged more total nitrogen than was applied to the basin. In June and July of 1976, nitrate concentrations from the drains often exceeded the total nitrogen applied to the basins. Presumably, NH_3 and organic-N was stored when wastewater was applied the previous winter and early spring until environmental factors such as higher temperature and soil aeration favored bacterial nitrification. With subsequent wastewater applications until mid-August, high concentrations of NO_3 reached the drains. When applied nitrogen increased in the fall of 1976, effluent nitrogen concentrations remained at lower levels possibly due to denitrification in the groundwater.

Biological nitrification-denitrification would appear to account for the nitrogen removals that occurred in 1977 and 1978 (see Figure 12). The adsorption and oxidation of the NH_3-N would be expected to occur at the surface or in the very upper layers of soil where oxygen and the nitrifying bacteria are plentiful. As the NO_3 were formed they would be expected to migrate with the renovated wastewater. Below the surface layer or within the shallow groundwater, anaerobic conditions would favor denitrification with conversion of the NO_3-N to gaseous end products which escape to the atmosphere. Although sampling of the effluent from the open drains could not be accomplished without some aeration, DO concentrations at the upper drains in 1977 were about 3.0 mg/1. The lower north and south drains had about 0.6 mg/1 of DO and the lower middle drain had 1.1 mg/1 of DO (mean values for eight readings). It should be noted that nitrogen was not as efficiently removed in the middle basin. Similarly low DO levels were measured in 1978.

Conditions that are conducive to denitrification existed at the site. The basins were constructed in a fine textured alluvial soil (silty clay loam) that was highly organic. Frequent wetting of the soil in 1977 and 1978, combined with a high water table may have allowed the necessary microorganisms to penetrate to below the surface where they could multiply under favorable pH (pH about 7.5) and temperature (about 17°C) conditions. Nitrogen removal, however, was not immediately accomplished when three-per-week applications began.

Figure 14 reveals the variation in nitrogen removal of the lower drains throughout the 1977 and 1978 application season. In July of 1977 soon after the construction activities, nitrogen discharged with the effluents from two basins actually exceeded the nitrogen applied. For example, the middle basin effluent of July 27 had a NO_3-N concentration 16.8 mg/1 and a total nitrogen of 18.4 mg/1, about double that of the applied wastewater (10). By mid-August, five or six weeks after wastewater applications began, denitrification was well-established in the north and south basins.

In 1978, nitrogen removal was even more impressive than in 1977. Even on the first wastewater application, nitrogen removal occurred and after about five weeks had reached a removal efficiency of about 80 percent or more on both

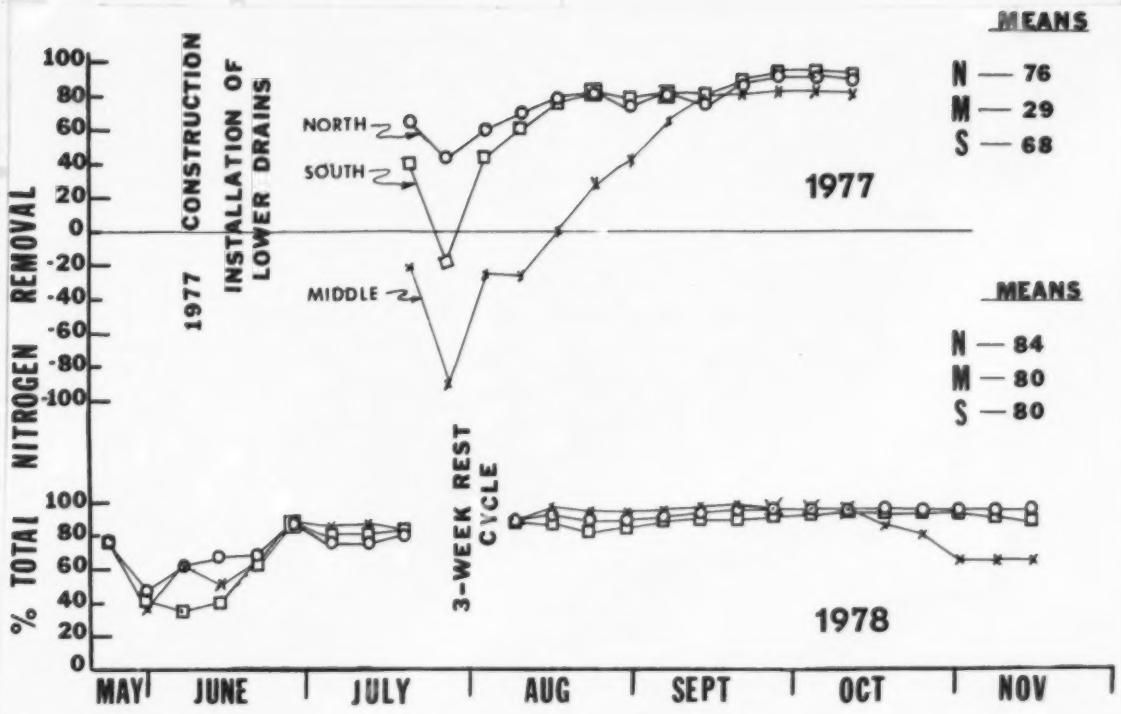

Figure 14. Total nitrogen removal efficiencies as calculated from the lower drain effluents and the influent from the stabilization pond for 1977 and 1978 (10,11).

sets of drains. The middle upper drain, however, only achieved a 44 percent average removal. A maturation period was not necessary in 1978 to initiate the denitrification process even though wastewater had not been applied for about six months. These data suggest that after sufficient numbers of denitrifiers have been established, long periods of inactivity may not be particularly disruptive to the nitrification-denitrification processes.

The various forms of nitrogen for the north basin in 1978 are shown in Figure 15. The figure exemplifies the data for the north and south drains with slightly higher nitrogen concentrations from the middle basin. From the higher NO_3-N concentrations in May and June for the drain effluent, it would appear that adequate populations of denitrifiers for effective nitrogen removals were slower to develop in the spring.

A three-week rest period in the summer did not appear to hamper effective nitrogen removals immediately after start-up. Only the upper drains showed slight increases in NO_3-N. After mid-October, increased NO_3-N in the upper drain effluents may have been the result of deeper DO penetrations into the basins. In November 1978, DO concentrations in excess of 1.0 mg/l were

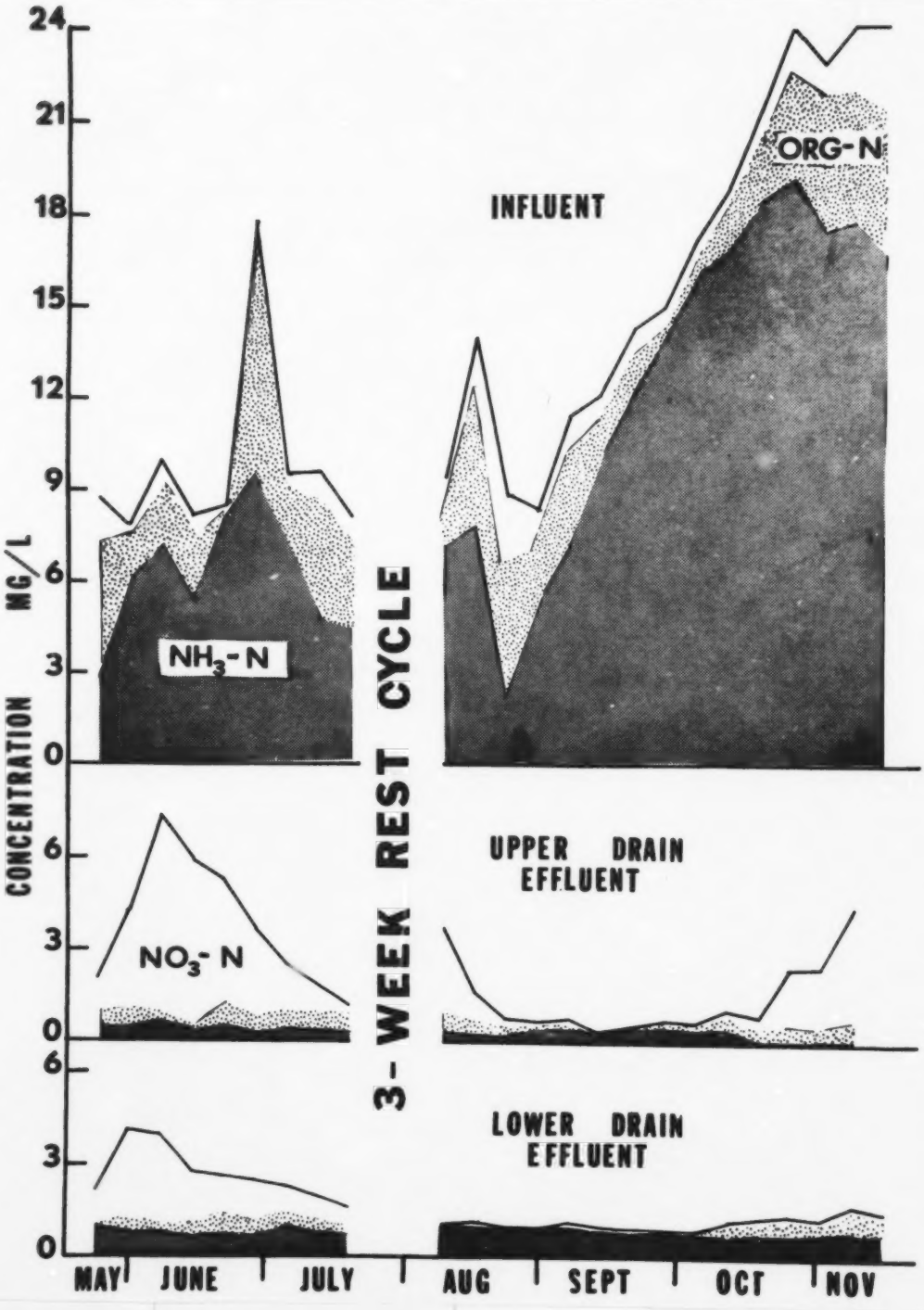

Figure 15. Variation in nitrogen forms for the north basin in 1978 (11).

noted in the lower north and south drains and more than 3 mg/l was noted from the lower middle drain (11).

A supply of carbon essential for the continued denitrifcation process would appear to be readily available in the soils at the site. Soil with more than 10 percent organic content plus carbon from the wastewater, algae and plant roots should be ample to sustain the efficient nitrogen removal for many years.

The real test of the rapid infiltration basins would be their effectiveness in renovating the wastewater to meet stringent effluent limits. From Table 6 it can be seen that the stabilization pond effluent would never have complied with NH_3-N standards which might pertain to a discharge to surface waters. By contrast, the pumped effluent from the lower drains of the pilot unit consistently met these requirements. Furthermore, a NO_3-N limit of 10 mg/l that might be imposed on discharges to a groundwater aquifer would also have been met with 1977 and 1978 operating conditions.

TABLE 6. COMPLIANCE OF NITROGEN FORMS WITH POTENTIAL DISCHARGE STANDARDS

Nitrogen form and sample	Limiting standard (mg/l)	Percent of samples violating standard					
				1977		1978	
		1975	1976	Upper	Lower	Upper	Lower
Ammonia Nitrogen							
Influent	1.1	96	98	100	100	100	100
N - Effluent	1.1	68	54	36	0	0	0
M - Effluent	1.1	72	45	73	0	65	0
S - Effluent	1.1	56	13	9	0	63	75
Influent	2.0	84	85	100	100	100	100
N - Effluent	2.0	56	28	0	0	0	0
M - Effluent	2.0	60	24	36	0	43	0
S - Effluent	2.0	40	3	9	0	0	0
Ammonia Nitrogen (un-ionized)							
Influent	0.02	--	--	100	100	100	100
N - Effluent	0.02	--	--	0	0	0	0
M - Effluent	0.02	--	--	50	0	52	0
S - Effluent	0.02	--	--	0	0	0	0
Nitrate Nitrogen							
Influent	10	4	0	0	0	0	0
N - Effluent	10	36	19	0	0	0	0
M - Effluent	10	36	19	9	8	9	0
S - Effluent	10	56	41	0	0	0	0

Samples for the 1975-76 years were collected from drains that were placed above the groundwater table. Only when the groundwater under the basins mounded sufficiently for the drains to flow, about a 24-hour period

after the weekly flooding, could the samples be collected. Consequently, the samples represented perhaps the worst effluent conditions measurable from drains yet still revealed a superior effluent quality. It may be that the nitrification-denitrification processes apparent in 1977 and 1978 existed in the groundwater below the drains in prior years and, consequently, were not routinely detected. Samples from monitoring wells in the area never reflected the high NO_3-N concentrations measured in the drain effluents.

The operation of the basins with more frequent wastewater applications, however, appears to have been the essential factor in reduction of the effluent NO_3-N. The anaerobic conditions necessary for denitrification would be enhanced when near-continuous wetting of the surface prevents aeration of the soil. The middle basin, with the higher NO_3-N effluent concentrations, maintained a higher infiltration rate, tended to dry, and aerated between wastewater applications despite the frequent floodings. With the three-per-week applications, effluent from the upper and lower drains showed marked reductions in NH_3-N without equivalent NO_3-N in the effluent.

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SECTION 9

WINTER OPERATING CONSTRAINTS

Continuous operation of infiltration-percolation systems, even in northern climates, has been considered as one of the major advantages of this type of land application system. Where winter operation has been practiced effectively, in some cases the wastewater has been applied periodically to infiltration basins. In other instances the water levels have been maintained in the basins so that seepage has been on a more-or-less continuous basis. The wastewater has generally been applied to the basins shortly after biological treatment, usually with trickling filters. Consequently, the wastewater probably contained considerable heat to prevent the soil from freezing under an ice cover.

In preparation for winter operations at the pilot basin in Brookings, the wastewater piping system was insulated with leaves and hay. Covers including manufactured insulating materials were, however, used at valves in the application system to allow access after heavy snowfall. A drain was installed to remove the water from the branch piping to the perimeter drain to prevent freezing of the piping after the filling cycle was completed. The sample box was also covered with an insulated shack to prevent freezing of the sump pumps and to offer some protection for research personnel.

The first experience with winter operation of the pilot basins at Brookings occurred in late November, 1975. The fall period had been unusually mild and the weekly flooding cycle had been followed regularly without difficulty. On November 19, rain preceded a severe blizzard that raged for two days with winds of about 45 kilometer (km)/hour (30 mile/hour) piling a 250 mm (10 in) snowfall into huge drifts. Traffic movement throughout the area was halted for two days.

The channel of Six-Mile Creek drifted full of snow, blocking the storm flow in the creek and causing the water level to rise in the sampling box. The sump pumps were flooded causing an electrical outage and water rose to the top of the sampling box. Thus, for the last November flooding of the pilot units, samples were not collected although the wastewater was applied to the snowfilled basins. The temperature of the wastewater was about 1°C (33°F) while the maximum air temperature on that day was -13°C (9°F) and dropped to -23°C (-10°F) during the night. The basins developed an ice cover soon after they were filled and a 75 mm (3 in) thickness of ice was noted the next day.

When the flooding cycle was repeated in early December about 100 mm (4 in) of ice covered the basins. It appeared that the weeds that existed in the basin served as anchors to prevent the ice from rising. Consequently, the

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wastewater applied to the basins did not cause the ice to float but rather to spread over the surface. As a result, an additional layer of ice was formed although because of mild temperatures the additional ice thickness was less than 25 mm (1 in). Flooding of the basins on a weekly cycle continued into January until ice accumulations nearly filled the basins.

Figure 16 includes photographs of the pilot basins during the winter operations including views of wastewater applied to the snow-filled basins. Weeds that apparently prevented the ice accumulations from floating are also shown. In one view, it will be noted that only a small volume of accumulated ice was melted on a subsequent flooding.

Figure 16. Winter operation of the pilot units.

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The experience with winter operation of the pilot units provided an opportunity to report (4) the problems that might be encountered with year-round operation of an infiltration system in this region. For example, the severe blizzards that occur, although infrequently, provide a constraint of unusual circumstances. Emergency storage of wastewater during such weather extremes would be essential.

Application of wastewater from the stabilization pond did not prove to be effective for melting the snow and ice accumulations. During winter, the wastewater temperature as it came from the stabilization pond was already near a freezing temperature. Continuous flooding at the time of the earliest hard freeze might have provided an insulating ice cover if snow had not accumulated in such large quantities from the preceding blizzard. At other facilities where winter operation has been reported, warmer effluents from secondary treatment plants have been applied directly to the land. At Brookings, the temperature of the effluent of the trickling filter plant is near 19°C (50°F), even through the most severe winter month of January. With a full-scale system, the effluent of this plant might be applied with more success directly to infiltration basins during the winter.

Removal of vegetation from the basins prior to winter might prevent the weeds from anchoring the ice. Since harvesting forage from a full-scale plant on a routine basis might prove entirely feasible under normal management, mowing could be routinely accomplished. The alfalfa in the middle basin died over the 1975-76 winter but the remaining grass produced a luxuriant growth throughout the summer of 1976.

The entire winter period when wastewater was not applied during the 1975-76 winter was from early January to early April, a period of less than three months. The April inundation of the pilot units was undertaken only to verify that wastewater could be applied and treated by that date although visual observations indicated that wastewater could have been applied at an earlier date. The quality of the effluent for that particular flooding, however, was very poor and the short-circuiting problem noted during the late 1975 season appeared to have been intensified over the winter. Table 7 contains the analytical data for the single spring flooding that occurred on April 6, 1976. Also, included are the data collected during a three-week special study in the spring of 1977.

To prepare for operation of the pilot basins into the 1976-77 winter, the grass and weeds in the basins were mowed in mid-September. Also, it was anticipated that greater depths of wastewater would be advantageous during the winter to provide a water layer under the ice and extend the infiltrative period. Consequently, wastewater volumes applied to the basins were increased and time between floodings extended to about a two-week interval. Unfortunately, the height of the banks of the basins did not allow a sufficient depth of wastewater to result in a floating ice cover. Similar ice-accumulation problems occurred and the last winter flooding was on December 19, 1976.

TABLE 7. EFFLUENT QUALITY IN THE SPRING AFTER WINTER SHUTDOWN

Constituent	Year*	Concentration-mg/1 Influent	North	Middle	South
BOD_5	1976	22	15	16	10
	1977	24	6.6	4.4	3.8
SS	1976	34	15	17	7
	1977	92	8.5	5.4	1.3
Ammonia Nitrogen	1976	16	4.3	5.0	2.2
	1977	18	2.4	2.7	1.3
Nitrate Nitrogen	1976	0.2	2.7	1.4	1.9
	1977*	4.1	9.3	4.6	3.6
Kjeldahl Nitrogen	1976	21	7.5	8.4	4.2
Ortho Phosphorus	1976	5.8	4.2	4.1	2.1
	1977	3.5	1.1	0.74	0.80
Total Phosphorus	1976	5.9	5.7	5.3	3.9
	1977	6.4	1.6	1.2	1.2
Conductivity (umho/cm at 25°)	1976	1100	1100	1200	1200
	1977	1500	1900	1600	1800
pH units (median value)	1976	----	----	----	----
	1977	8.2	7.6	7.7	7.6

*All 1976 data and 1977 nitrates data are for only a single flooding.

In the following spring of 1977, wastewater was applied to the pilot units on a weekly basis for three weeks starting on April 5. Effluent quality (Table 7) was satisfactory to meet most discharge requirements although effluent NH_3-N concentrations were still greater than 2 mg/1. Some spring tilling of the soil would appear to be beneficial since traces of algae were observed in the effluent from all three basins. It should be recognized that the data included in Table 7 represented the quality from the upper drains of the pilot basin which were used at that time since the deeper drains were installed in the following three months. Later experience would suggest that improved quality could be expected from deeper drains.

Ice accumulations proved to be the major operating constraint of the pilot basins. Without a source of wastewater that contains some heat, the presence of large quantities of snow in the basins resulted in slush that froze quickly when the air temperature was well below freezing. If the dikes of the pilot basins had been higher, it might have been possible to maintain water under the ice continuously. It should be recognized, however, that ice on shallow lakes in South Dakota frequently exceeds a thickness of 0.6 m (2 ft). Preparation of basin surfaces to form a ridge-and-furrow application area might also be advantageous to extend operation into the severe winter. The ridges might support ice to insulate the soil in the furrows

where infiltration could continue into the winter.

From observations and experience during the winter operations, it appeared that the ice problems that occurred with the stabilization pond effluent would not be overcome with operational changes at the existing pilot basins. Wastewater applications were continued into December although reduced volumes were applied because of accumulated ice. Historically, the annual average air temperature in the Brookings area drops to freezing about November 12 so it would appear that wastewater applications from stabilizations ponds could safely continue on a regular basis for at least a month beyond that date. Consequently, existing stabilization ponds in South Dakota which are frequently designed with six-months of detention could probably be operated to provide the preapplication treatment and the necessary emergency storage capacity to carry through the most severe winters.

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APPENDIX

TABLE A-1. SUMMARY OF NITROGEN AND PHOSPHORUS DATA PILOT INFILTRATION-PERCOLATION BASINS BROOKINGS, SOUTH DAKOTA MAY 24, 1978 - NOVEMBER 15, 1978

Determination (mg/l except as noted)	No. of samples Old[a]	No. of samples New[b]	Maximum Old	Maximum New	Minimum Old	Minimum New	Median Old	Median New	Mean Old	Mean New
Kjeldal Nitrogen										
Influent	--	24	----	23	----	6.8	----	11	----	13.01
N-Effluent	23	24	1.3	1.5	0.30	0.80	0.70	1.1	0.77	1.12
M-Effluent	23	24	10	1.6	1.3	0.40	2.8	0.70	4.19	0.76
S-Effluent	19	24	2.0	1.6	0.60	1.2	1.6	1.4	1.44	1.41
Ammonia Nitrogen										
Influent	--	24	----	19	----	2.31	----	7.6	----	10.25
N-Effluent	23	24	0.64	1.0	0.05	0.68	0.38	0.81	0.34	0.85
M-Effluent	23	24	7.9	0.57	0.38	0.18	1.7	0.37	3.15	0.36
S-Effluent	19	24	1.6	1.5	0.20	0.80	1.2	1.2	1.08	1.20
Organic Nitrogen										
Influent	--	24	----	7.68	----	<0.1	----	2.3	----	2.78
N-Effluent	23	24	0.75	0.63	<0.1	<0.1	0.44	0.32	0.43	0.27
M-Effluent	23	24	2.27	1.37	0.2	<0.1	0.94	0.38	1.03	0.40
S-Effluent	19	24	0.83	0.46	<0.1	<0.1	0.26	0.21	0.34	0.23
Nitrate Nitrogen										
Influent	--	24	----	2.6	----	0.4	----	0.9	----	1.0
N-Effluent	23	24	6.5	2.9	<0.1	<0.1	0.9	0.2	1.6	0.6
M-Effluent	23	24	10.5	8.3	0.6	<0.1	2.6	0.7	3.9	2.0
S-Effluent	19	24	4.3	5.0	<0.1	<0.1	0.2	0.3	0.9	0.9
Total Nitrogen										
Influent	--	24	----	24	----	8.0	----	12	----	14.0
N-Effluent	23	24	7.5	4.1	0.35	0.91	1.9	1.4	2.40	1.75
M-Effluent	23	24	20.5	9.0	3.1	0.49	5.0	1.6	8.12	2.79
S-Effluent	19	24	6.1	6.5	0.73	1.3	1.8	1.8	2.36	2.31
Ortho-Phosphorus										
Influent	--	24	----	3.8	----	0.53	----	2.8	----	2.63
N-Effluent	23	24	1.0	0.26	0.40	0.15	0.68	0.21	0.73	0.21
M-Effluent	23	24	3.3	0.46	1.1	0.32	1.7	0.39	2.00	0.39
S-Effluent	19	24	0.70	0.35	0.21	0.16	0.46	0.27	0.46	0.27
Total Phosphorus										
Influent	--	24	----	5.4	----	1.5	----	3.4	----	3.36
N-Effluent	23	24	1.0	0.29	0.40	0.17	0.71	0.24	0.74	0.24
M-Effluent	23	24	3.6	0.46	1.1	0.35	1.8	0.41	2.19	0.41
S-Effluent	19	24	0.95	0.36	0.36	0.20	0.61	0.31	0.58	0.30

[a] Old drains are the upper drains installed in 1974.

[b] New drains are lower drains installed in 1977.

TABLE A-2. SUMMARY OF INORGANIC CHEMICAL DATA PILOT INFILTRATION-PERCOLATION BASINS BROOKINGS, SOUTH DAKOTA MAY 24, 1978 - NOVEMBER 15, 1978

Determination	No. of samples Old[a]	No. of samples New[b]	Maximum Old	Maximum New	Minimum Old	Minimum New	Median Old	Median New	Mean Old	Mean New
(mg/l except as noted)										
Conductivity (umhos/cm)										
Influent	--	24	2000	2000	----	1500	----	1900	----	1850
N-Effluent	23	24	2300	2100	1700	1800	2100	2000	2100	1971
M-Effluent	23	24	2100	2200	1600	1700	1900	2000	1901	1960
S-Effluent	19	24	2400	2100	1600	1600	2100	1900	2063	1941
Total Hardness										
Influent	--	23	----	65	----	47	----	51	----	531
N-Effluent	22	23	72	78	59	62	66	65	652	658
M-Effluent	22	23	65	69	52	60	57	65	567	640
S-Effluent	18	23	80	72	53	59	74	62	711	624
Sodium										
Influent	--	23	----	226	----	14	----	19	----	184
N-Effluent	22	23	23	22	17	17	21	18	209	186
M-Effluent	22	23	23	22	18	15	19	19	194	193
S-Effluent	18	23	23	22	14	15	20	18	197	184
Chlorides										
Influent	--	24	----	30	----	21	----	26	----	254
N-Effluent	23	24	30	29	23	24	27	27	268	262
M-Effluent	23	24	29	29	22	22	26	27	257	259
S-Effluent	19	24	30	30	20	21	26	27	261	259
Alkalinity										
Influent	--	23	----	37	----	29	----	32	----	323
N-Effluent	22	23	51	42	37	36	44	38	438	387
M-Effluent	22	23	45	47	27	37	33	41	337	407
S-Effluent	18	23	57	43	33	33	48	37	471	373
Total Residue										
Influent	--	20	----	136	----	117	----	129	----	1277
N-Effluent	19	20	153	139	130	127	143	136	147	1352
M-Effluent	19	20	142	145	122	126	131	138	131	1368
S-Effluent	15	20	161	141	112	126	149	133	1446	1328
pH units										
Influent	--	23	----	8.6	----	7.6	----	7.9	----	----
N-Effluent	22	23	7.7	7.6	7.2	7.2	7.4	7.3	----	----
M-Effluent	22	23	7.6	7.6	7.1	7.2	7.4	7.3	----	----
S-Effluent	18	23	7.6	7.6	7.2	7.2	7.4	7.4	----	----

[a] Old drains are the upper drains installed in 1974.

[b] New drains are lower drains installed in 1977.

TABLE A-3. SUMMARY OF NITROGEN DATA
PILOT INFILTRATION-PERCOLATION BASINS BROOKINGS, SOUTH DAKOTA
JUNE 11,-DECMEBER 16, 1975; MAY 26-NOVEMBER 22, 1976; and JULY 20-OCTOBER 12, 1977

	1975 Concentration-mg/l*				1976 Concentration-mg/l*				Number of Samples		1977 Concentration-mg/l*					
	Number of Samples	Max.	Min.	Mean	Number of Samples	Max.	Min.	Mean			Max.		Min.		Mean	
									Old*	New*	Old	New	Old	New	Old	New
Kjeldahl Nitrogen																
Influent	21	36	4.9	12	27	20	2.7	10	11	13	19	19	8.7	7.3	13	12
N-Effluent	21	12	1.4	3.9	27	5.3	1.2	2.5	11	13	2.9	1.6	1.3	0.90	1.8	1.2
M-Effluent	21	8.9	1.4	4.3	27	7.6	1.1	2.7	11	13	4.5	2.2	1.6	0.95	3.1	1.3
S-Effluent	21	5.7	1.1	2.7	27	2.1	0.7	1.3	10	13	3.1	1.8	0.67	1.2	1.3	1.5
Drain Tile	5	0.89	0.74	0.84	21	2.1	0.51	1.0	--	--	----	----	----	----	----	----
Ammonia Nitrogen																
Influent	25	33	0.84	10	26	18	0.85	7.3	11	13	17	17	6.2	4.7	11	10
N-Effluent	25	11	0.14	3.5	27	3.1	0.08	1.4	11	13	1.6	0.8	0.60	0.48	1.0	0.62
M-Effluent	25	9.6	0.29	3.2	26	5.4	0.13	1.4	11	13	4.5	1.1	0.81	0.55	2.2	0.75
S-Effluent	25	8.1	0.09	2.3	27	1.8	0.22	0.65	10	13	2.3	1.1	0.18	0.57	0.60	0.86
Drain Tile	4	0.21	0.07	0.14	21	0.86	0.00	0.21	--	--	----	----	----	----	----	----
Organic Nitrogen																
Influent	21	11	1.1	4.4	26	6.3	0.63	3.3	11	13	3.1	3.2	<0.1	<0.1	1.7	1.9
N-Effluent	21	3.1	<0.1	1.4	27	2.9	0.05	1.1	11	13	1.6	1.0	0.16	<0.1	0.82	0.66
M-Effluent	20	4.5	0.17	1.8	26	3.0	0.27	1.3	11	13	1.6	1.1	<0.1	<0.1	0.96	0.63
S-Effluent	19	2.7	0.56	1.2	27	1.7	0.12	0.93	10	13	1.0	1.1	0.33	0.31	0.73	0.67
Drain Tile	3	0.7	0.62	0.69	20	1.7	0.18	0.77	--	--	----	----	----	----	----	----
Nitrate Nitrogen																
Influent	25	13	<0.1	1.4	27	1.3	0.07	0.59	11	13	0.86	0.86	0.22	0.22	0.47	0.45
N-Effluent	25	18	1.0	8.7	27	19	0.50	5.8	11	13	4.0	3.7	0.49	0.45	1.6	1.3
M-Effluent	25	16	1.5	7.7	27	19	2.3	6.9	11	13	10	16	3.4	1.6	5.6	6.2
S-Effluent	25	25	3.1	11	27	25	2.8	9.9	10	13	5.2	9.55	0.76	0.29	1.9	1.8
Drain Tile	5	13	4.9	8.7	21	15	1.0	5.2	--	--	----	----	----	----	----	----
Total Nitrogen																
Influent	21	36	6.7	14	27	21	3.3	10	11	13	19	19	9.1	7.6	13	12
N-Effluent	21	27	4.4	13	27	22	1.8	8.4	11	13	6.2	5.35	1.9	1.5	3.4	2.6
M-Effluent	21	22	4.5	11	27	21	3.6	9.7	11	13	13	18	6.4	2.8	8.8	7.6
S-Effluent	21	31	4.5	13	27	26	3.9	11	10	13	6.4	11	1.8	1.5	3.2	3.3
Drain Tile	--	----	----	----	21	15	1.8	6.1	--	--	----	----	----	----	----	----

*Concentration expressed in milligrams per liter.

*Old drains are the upper drains installed in 1974

*New drains are the lower drains installed in 1977.

TABLE A-4. SUMMARY OF SELECTED ANALYTICAL DATA
PILOT INFILTRATION-PERCOLATION BASINS BROOKINGS, SOUTH DAKOTA
JUNE 11-DECEMBER 16,1975; MAY 26-NOVEMBER 22, 1976; AND JULY 20-OCTOBER 12, 1977

	1975 Concentration-mg/l*				1976 Concentration-mg/l*				1977 Concentration mg/l*							
	Number of samples	Max.	Min.	Mean	Number of samples	Max.	Min.	Mean	Samples Old*	Samples New*	Max. Old	Max. New	Min. Old	Min. New	Mean Old	Mean New
BOD5																
Influent	27	61	9.8	29	27	58	4.6	23	11	13	44	44	6.5	6.5	22	21
N-Effluent	27	25	2.4	8.9	27	11	0.4	4.3	11	13	6.6	2.8	0.5	0.3	3.2	1.1
M-Effluent	27	25	3.0	11	27	10	0.6	5.1	11	13	9.4	3.7	1.8	0.1	4.6	1.7
S-Effluent	27	15	2.0	6.8	27	8.0	0.4	1.8	10	13	6.3	3.1	0.4	0.6	2.9	1.2
Drain Tile	--	----	---	----	3	1.7	1.0	1.2	--	--	----	----	---	---	----	----
Suspended Solids																
Influent	27	79	11	43	27	71	16	38	11	13	44	49	8.2	8.2	23	27
N-Effluent	27	27	0.4	7.0	27	11	<0.1	4.0	11	13	9.8	4.6	0.4	<0.1	4.1	1.9
M-Effluent	27	36	0.4	9.7	27	14	0.4	5.8	10	13	32	10.4	<0.1	<0.1	8.2	2.4
S-Effluent	27	26	<0.1	5.8	27	6.0	<0.1	2.3	10	13	4.6	2.8	0.8	0.4	1.9	1.7
Drain Tile	--	----	---	----	19	7.4	<0.1	2.4	--	--	----	----	---	---	----	----
Specific Conductance (umho/cm)																
Influent	28	1800	1500	1600	23	2000	1500	1800	11	13	2000	2000	1700	1700	1900	1900
N-Effluent	28	2000	1600	1800	23	2200	1800	2000	11	13	2300	2100	1800	1800	2100	2000
M-Effluent	28	2000	1600	1800	23	2200	1700	1900	11	13	2100	2200	1700	1800	1900	2100
S-Effluent	28	2000	1500	1800	23	2400	1800	2200	10	13	2200	2300	1800	1800	2000	2000
Drain Tile	--	----	---	----	16	2200	1800	2100	--	--	----	----	---	---	----	----
Total Phosphorus																
Influent	25	7.1	1.2	4.2	27	8.7	1.2	3.5	11	13	4.3	4.3	2.4	2.4	3.2	3.5
N-Effluent	21	4.9	0.95	2.1	27	4.2	0.91	1.6	11	13	2.4	1.1	0.76	0.14	1.5	0.40
M-Effluent	21	6.1	0.85	2.2	27	2.3	0.94	1.5	11	13	2.9	1.7	1.7	0.23	2.2	0.61
S-Effluent	21	3.7	0.75	1.7	27	2.0	0.68	1.1	10	13	1.7	0.63	0.63	0.19	0.98	0.32
Drain Tile	2	0.74	0.67	0.71	20	1.2	0.25	0.5	--	--	----	----	----	----	----	----
Ortho Phosphorus																
Influent	25	6.7	0.44	3.3	27	5.8	0.44	2.6	11	13	3.8	3.8	1.8	1.8	2.9	2.9
N-Effluent	25	4.0	0.68	1.6	27	2.3	0.86	1.4	11	13	2.4	0.43	0.58	0.11	1.3	0.24
M-Effluent	25	3.3	0.78	1.7	27	2.2	0.86	1.3	11	13	2.4	0.72	1.3	0.19	1.9	0.47
S-Effluent	25	3.1	0.57	1.4	27	1.3	0.67	1.2	10	13	1.3	0.32	0.60	0.14	0.88	0.25
Drain Tile	6	0.84	0.57	0.68	21	0.76	0.25	0.45	--	--	----	----	----	----	----	----
pH Units																
Influent	--	----	----	----	26	9.2	7.8	----	11	13	8.1	8.5	7.7	7.7	----	----
N-Effluent	--	----	----	----	26	7.4	6.9	----	11	13	7.9	7.6	7.2	7.2	----	----
M-Effluent	--	----	----	----	26	7.6	7.1	----	11	13	7.7	7.7	7.1	7.4	----	----
S-Effluent	--	----	----	----	26	7.5	6.9	----	10	13	7.7	7.6	7.1	7.5	----	----
Drain Tile	--	----	----	----	20	7.6	7.2	----	--	--	----	----	----	----	----	----

*Concentration expressed in milligrams per liter except as noted.
*Old drains are the upper drains installed in 1974.
*New drains are the lower drains installed in 1977.